Analysis of Energy Conservation Standards for Small Electric Motors

Technical Support Document

Final Draft

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ABBREVIATIONS AND ACRONYMS

AC	alternating current
Btu	British thermal unit
Btu/h	British thermal units per hour
CAPM	Capital Asset Pricing Model
CSCR	capacitor-start, capacitor-run
CSIR	capacitor-start, induction-run
DC	direct current
DOE	Department of Energy
EIA	Energy Information Administration
EPCA	Energy Policy and Conservation Act
ERP	equity risk premium
GDP	gross domestic product
hertz	Hz
hp	horsepower
HVAC	heating, ventilation, and air conditioning
Hz	hertz
I^2R	the expression of heat loss in watts where I is measured current and R is resistance
LBNL	Lawrence Berkeley National Laboratory
LCC	life-cycle cost
NAICS	North American Industry Classification System
NEMA	National Electrical Manufacturers Association

NPV	net present value
ODP	open drip-proof
OEM	original equipment manufacturer
PSC	permanent-split capacitor
PU	per unit
Quad (one)	quadrillion (10^{15}) British thermal units (Btu) or 293.1 billion kilowatt hours
rpm	revolutions per minute
rps	revolutions per second
SMMA	Small Motors and Motion Association

EXECUTIVE SUMMARY

PURPOSE

Section 346(b)(1) of the Energy Policy and Conservation Act (EPCA) (42 U.S.C. 6317(b)(1)) requires the Department of Energy (DOE or the Department) to determine whether energy conservation standards for certain small electric motors would be technologically feasible and economically justified, and would result in significant energy savings. To have a basis for a determination, the Department performed the analysis described in this document.

SCOPE OF MOTORS ANALYZED

Under section 340(13)(F) of EPCA, 42 U.S.C. 6311(13)(F), the term "small electric motor" means a National Electrical Manufacturers Association (NEMA) general-purpose, alternating-current, single-speed, induction motor, built in a two-digit frame-number series in accordance with NEMA Standards Publication MG1-1987, "Motors and Generators." The two-digit frame series encompasses NEMA frame sizes 42, 48, and 56. The horsepower ratings for the two-digit frame series range from 1/4 to three horsepower. These motors operate at 60 Hertz and have either a single-phase or a three-phase (polyphase) electrical design. Section 346(b)(3) of EPCA, 42 U.S.C. 6317(b)(3), also states that a standard prescribed for small electric motors shall not apply to any small electric motor that is a component of a covered product under section 332(a) of EPCA or covered equipment under section 340.

Among single-phase, two-digit frame motors, only capacitor-start motors—including both capacitor-start, induction-run (CSIR) and capacitor-start, capacitor-run (CSCR) motors—can meet the torque requirements for NEMA general-purpose motors. Among three-phase, small motors, servo motors do not meet the NEMA performance requirements for general-purpose motors. Hence, the analysis covers only non-servo three phase small motors. Market research indicates that the annual commercial sales volume of CSIR, CSCR, and polyphase small motors meeting the EPCA definition is approximately four million units for capacitor-start (with 95% CSIR and 5% CSCR) and one million units for polyphase designs. These motors are used in a wide variety of commercial and industrial applications, with the largest being pumping equipment and commercial/industrial heating, ventilating, and air conditioning equipment rated over 240,000 British thermal units per hour (Btu/h).

METHODOLOGY

The analysis consists of five major elements: (1) market research that defines the commercial and industrial applications of small motors; (2) engineering analysis that estimates the relationship between efficiency and cost; (3) life-cycle cost (LCC) analysis which estimates the costs and benefits to users from increased efficiency in small motors; (4) national energy savings analysis that determines the potential energy savings on a national scale; and (5) national consumer impacts analysis that estimates potential direct economic costs and benefits that may result from small motor energy conservation standards. The Department conducted actual independent testing of a sample of motors to provide input data for these analyses. In conducting the engineering and LCC analyses, DOE used two sets of data. It obtained the first set from the motor testing and design costing conducted by an independent motor industry expert. The

Department obtained the second set of engineering input data from consultations with a working group comprised of major small motor manufacturers.

SUMMARY OF RESULTS

Energy-efficiency-enhancing design options that DOE considered have the energy savings potentials described below. The Department presents a range of national economic impacts for the considered small motors. The Department presents a range of results because it obtained cost and efficiency information through two sets of engineering data, as described above. Moreover, the Department considered four scenarios based on different assumptions about shipment growth and base case efficiency trends.

Capacitor-start, induction-run motors

The analysis based on DOE's motor testing and costing shows potential cumulative energy savings from motor efficiency improvement ranging from 0.47 to 0.59 quadrillion Btu (quad) of energy over the period 2010 to 2040 for motors sold between 2010 and 2030. The corresponding cumulative economic benefit for consumers, expressed in terms of net present value (NPV) of benefits, ranges from $0.28 billion to $0.35 billion.

Analysis based on average data from the NEMA/ Small Motors and Motion Association (SMMA) working group indicates lower potential energy savings and economic benefits. The highest savings scenario, which in this case refers to the stack-change design option, shows energy savings of 0.21 quad with an NPV of $0.04 billion. In the scenario with least savings, the all design-options have negative NPV.

Polyphase motors

The analysis based on DOE's motor testing and costing shows cumulative energy savings from steel-grade changes ranging from a low of 0.14 quad to a high of 0.19 quad over the period 2010 to 2040 for motors sold between 2010 and 2030. The corresponding cumulative NPV range is from $0.08 billion to $0.11 billion.

For polyphase motors, DOE did not estimate national impacts using the NEMA/SMMA data because the manufacturers' analysis was based on a 1/2 horsepower motor that is not representative of the size of motors in this product class which are more typically one horsepower in size.

CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

Under 346(b)(1) of the Energy Policy and Conservation Act (EPCA), 42 U.S.C. 6317(b)(1), the Department of Energy (DOE or the Department) is required to determine whether energy conservation standards for certain small electric motors would be technologically feasible and economically justified, and would result in significant energy savings. The purpose of this draft analysis is to provide a basis on which the Department can make its determination.

Under section 340(13)(F) of EPCA, 42 U.S.C. 6311(13)(F), the term "small electric motor" means a National Electrical Manufacturers Association (NEMA) general-purpose, alternating-current, single-speed induction motor, built in a two-digit frame-number series in accordance with NEMA Standards Publication MG1-1987, "Motors and Generators." The two-digit frame series encompasses NEMA frame series 42, 48, and 56. The horsepower ratings for the two-digit frame series range from 1/4 to three horsepower. These motors operate at 60 Hertz and have either a single-phase or a three-phase (also known as "polyphase") electrical design.

Typical applications for such small electric motors include pumps, fans and blowers, woodworking machinery, conveyors, air compressors, commercial laundry equipment, service industry machines, food processing machines, farm machinery, machine tools, packaging machinery, and major residential and commercial equipment.

EPCA section 346(b)(3) states that any energy conservation standard prescribed under subsection (b)(2) "shall not apply to any small electric motor which is a component of a covered product under section 322(a) or a covered equipment under section 340." Such covered products and equipment that contain small electric motors include residential air conditioners and heat pumps, furnaces, refrigerators and freezers, clothes washers and dryers, and dishwashers; and commercial package air conditioning and heating equipment, packaged terminal air conditioners and heat pumps, and warm-air furnaces. EPACT 2005 increased the number of products covered under EPCA. In response the Department adjusted its estimates and forecasts of the shipments of considered small motors to exclude those motors that are a component of these newly covered products. Newly covered products include commercial/industrial heating, ventilating, and air-conditioning equipment rated from 240,000 to 760,000 British thermal units per hour (Btu/h), and commercial clothes washers.

As a result of the above definitions and exclusions, small electric motors covered by EPCA section 346(b)(1) only comprise about four percent of the total shipments of small electric motors. Nevertheless, these motors, which the Department identifies here as "considered small motors," account for a major portion of the energy consumed by the total population of small motors because of their size and use.

1.2 OVERVIEW OF CONSIDERED SMALL MOTORS

As described above, the motors considered in this report are a subset of the total population of small electric motors. Further, the term "general purpose" in the EPCA definition[a] of a small motor is tied to the NEMA Standards Publication MG1-1987 performance requirements that NEMA established for general purpose motors, such as the minimum levels for breakdown and locked-rotor torque for small electric motors presented in MG1-1987 paragraph 12.32.

Among considered, single-phase, two-digit motors, those motors with shaded-pole, permanent-split capacitor designs, and those with split-phase designs do not meet the torque requirements of NEMA general-purpose motors. Capacitor-start motors, including both capacitor-start, induction-run (CSIR) and capacitor-start, capacitor-run (CSCR) motors, can provide the torque requirements for NEMA general purpose motors. Other single-phase motors, such as universal, drip-proof, and series alternating current (AC) motors, are designed for definite or special-purpose applications.

The CSCR motor is not interchangeable with the CSIR motor in most cases, because of differences in size and starting torque. The addition of a second running capacitor to the motor changes the dimensional envelope of the motor but not the frame size. In this analysis, the Department considers the CSIR and CSCR motors as separate product classes, but analyzes in detail only CSIR motors since they represent 95% of sales of capacitor start motors. Although CSIR and CSCR are not interchangeable for all applications, there may be some applications for which the CSCR offers a higher-efficiency alternative to a CSIR motor.

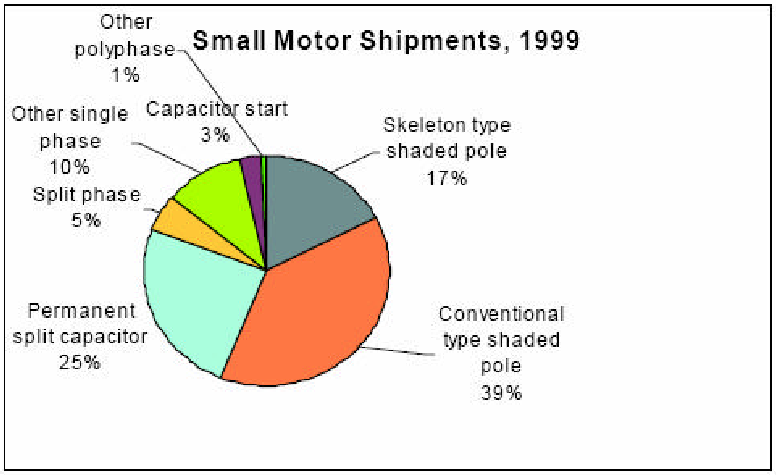
Among polyphase, small motors, synchronous-stepper motors cannot provide the torque requirements of NEMA general-purpose motors, while polyphase servo motors are for definite purpose applications. Polyphase non-servo motors do meet the NEMA requirements for general purpose motors.

For the purposes of this analysis, the considered small electric motors that meet the EPCA definition fall into three product classes:

- Single-phase, capacitor-start, induction-run motors
- Single-phase, capacitor-start, capacitor-run motors
- Polyphase (non-servo) motors

[a] EPCA does not define the term "general purpose motor," although it does define the terms "definite purpose motor" and "special purpose motor." According to EPCA, "definite purpose motor" means "any motor designed in standard ratings with standard operating characteristics or standard mechanical construction for use under service conditions other than usual or for use on a particular type of application and which cannot be used in most general purpose applications." (42 U.S.C. 6311 (13)(B)). Likewise, "special purpose motor" means "any motor, other than a general purpose motor or definite purpose motor, which has special operating characteristics or special mechanical construction, or both, designed for a particular application." (42 U.S.C. 6311 (13)(C)). Consequently, the Department must derive the term "general purpose" by eliminating those definite and special purpose motors, and subsequently must define the term within the context of NEMA performance characteristics that can operate successfully in many different applications.

These classes accounted for close to four percent of total domestic shipments (capacitor start – three percent and other polyphase – one percent) of all fractional horsepower motors in 1999 (Figure 1.1). This is because the largest categories of small motors do not fit the starting torque requirements for "general purpose" motors as defined by NEMA Standards Publication MG1-1987.



Source: US Census Bureau, Current Industrial Reports, Motors and Generators -- MA335H

Figure 1.1 Total Domestic Shipments of Fractional Horsepower Motors in 1999

Not all capacitor-start and polyphase non-servo motors are NEMA general-purpose motors. Those in the "definite-purpose" category include many motors used for fans and blowers and specific types of pumps.

1.3 APPLICATIONS FOR CONSIDERED SMALL MOTORS

The applications for the considered small motors are listed below:

Table 1.1 Major Applications for Considered Small Motors

Pumps and pumping equipment
Commercial and industrial HVAC / refrigeration equipment
Farm machinery
Conveyors
Industrial and commercial fans and blowers
Machine tools
Textile machinery
Woodworking machinery
Food products machinery
Air and gas compressors
Packaging machinery
General industrial machinery
Commercial laundry machinery
Service industry machinery

Many motors used in pumps and pumping equipment and industrial and commercial fans and blowers are definite-purpose motors, but a significant number of general-purpose motors are also used. In commercial and industrial heating, ventilating, and air-conditioning (HVAC) equipment, the HVAC equipment that is covered under other EPCA requirements (section 340) is rated at less than 760,000 Btu per hour (cooling capacity).

1.4 STUDY APPROACH

The Department's analyses consisted of five major components:

- Market research to better understand usage patterns of considered motors;
- Engineering analysis to estimate the impact on efficiency and cost of feasible design options;
- Life-cycle cost (LCC) analysis to estimate the benefits and costs of efficiency improvement for end-users of small motors;
- National energy savings analysis to estimate the potential national energy savings from efficiency improvement of considered motors; and
- National consumer impacts analysis to estimate the potential direct economic costs and benefits resulting from efficiency improvement of considered motors.

In the chapters that follow, this report first discusses the general characteristics of small motors in Chapter 2, and then discusses the market research, engineering analysis, and LCC analysis in Chapters 3 through 5 respectively. Chapter 6 discusses both the national energy saving and national consumer economic impacts. Lastly, Chapter 7 provides the summary and concluding commentary of this report.

CHAPTER 2. GENERAL CHARACTERIZATION OF SMALL ELECTRIC MOTORS

2.1 THREE-PHASE, SQUIRREL-CAGE INDUCTION MOTORS

Three-phase, squirrel-cage induction motors are the prime movers for the majority of commercial and industrial sector mechanical applications requiring more than a few horsepower, and in many smaller applications as well. The typical three-phase induction motor employs a wound stator and a "squirrel cage" rotor. Magnetic force acting between the stator and rotor units produces motor torque. The stator consists of a hollow cylindrical core formed by a stack of thin steel laminations. Insulated copper windings are assembled into slots formed around the inner circumference of the core. The stator winding carries current through one slot and then back though a companion slot located approximately one pole pitch distant from the first. For a two-pole motor, the pole pitch is half the circle, while for four- or six-pole machines it is one-quarter or one-sixth of the circle, respectively.

The rotor unit consists of a laminated steel core press fitted to the steel shaft. Like the stator, the rotor core also has windings set into slots, but these are deployed around its outer circumference. Moreover, in the squirrel-cage rotor configuration, the rotor windings consist of solid conductor bars that are interconnected at either end with solid-conductor end rings. Absent the laminated steel core, this assembly of bars and end rings would look like a “squirrel cage”; hence the nomenclature for this very sturdy and cost-effective construction.

When the stator windings are energized by a three-phase electrical source, a radially directed magnetic flux is established in the “air gap” between the rotor and the stator. This flux rotates at a speed determined by the electrical frequency and number of poles given by the stator-winding configuration. For example, with 60-hertz (Hz) excitation and a two-pole (or one-pole-pair) winding, the flux rotates at a so-called “synchronous” speed of 60 revolutions per second (rps) or 3,600 revolutions per minute (rpm). When an application exerts a torque on the motor, a difference arises between the synchronous speed and the actual speed of the motor which is termed “slip.” Thus the fully loaded speed is slightly less than the synchronous motor speed. The flux produced by the energized stator windings envelops the rotor cage bars and, due to its motion, induces current to flow in these conductors. The interaction of the rotating stator flux and the rotor bar currents develops motor-drive torque.

Important characteristics of the three-phase squirrel cage induction motor are simplicity, ruggedness, inherently high starting torque (without the start-assisting devices required for single-phase motors), and the potential to achieve high efficiency. Compared with larger motors, the efficiency of small (one horsepower and below), three-phase induction motors declines rapidly as the load drops below 70 percent of rated load.

Polyphase motors in a two-digit NEMA frame size range from 1/4 horsepower to three horsepower, although the majority are one horsepower or less. They are available in two-, four-, or six-pole configurations (corresponding to speeds of 3500, 1750, or 1150 rpm, respectively). A four-pole configuration is the most common.

2.2 SINGLE-PHASE, SQUIRREL-CAGE INDUCTION MOTORS

The basic principal of operation of a single-phase, squirrel-cage, induction motor is similar to a three-phase induction motor. A rotating magnetic field is easily established with three-phase excitation of motor windings, as described in the preceding subsection. In a single-phase induction motor, two counter-rotating fields are produced which develop equal and opposite rotor torque components when the motor is at standstill. However, if means are provided to urge rotation in one direction or the other, net torque will be developed to sustain the rotation and drive the attached load. While the electromagnetic torque acting on the rotor of a three-phase motor is relatively smooth and free from pulsating disturbances, this is not the case in the single-phase motor. In this instance, the torque may pulsate from zero to a maximum value at twice the power-line frequency—e.g., 120 Hz. In most applications, this is of little consequence, as the inertia of the motor and the driven load act to smooth out the torque pulsations.

The basic construction of the single-phase induction motor includes a rotor and stator; each contains a stack of electromagnetic grade steel laminations, as previously described for the three-phase motor. The "squirrel cage" rotor has a series of aluminum bars cast lengthwise into the rotor laminations. These bars are connected with rings located at each end of the stack. The stator laminations contain a series of slots for the windings that are aluminum or copper wire. Two sets of windings are provided, at a 90°-phase difference. The “main” or “run” winding operates directly from line current, and stays energized as long as the motor is running.

Single-phase motors are categorized according to the way the “start and run,” “secondary,” or “auxiliary” winding is used for starting the motor and then running it at normal speed. Widely used single-phase motor categories are:

- The split-phase motor -- This configuration is the least costly. The start winding has a higher resistance-to-reactance ratio than the main winding, which is achieved by using a relatively small diameter wire. This reduces both the amount and the cost of the copper in the start winding and the space taken up in the stator slots by this winding.

- The CSIR motor -- This configuration is a comparatively low-efficiency motor that provides higher starting torque than the split-phase motor.

- The permanent-split capacitor (PSC) motor -- This configuration has a high potential efficiency depending on the design.

- The CSCR motor -- This has an efficient run configuration, with a large capacitance at start-up providing a large starting torque. The start capacitance is typically three to five times the size of the run capacitor, but can be packaged compactly, because continuous operation (and the resulting heat dissipation) is not a consideration.

Split-phase and CSIR motors use the secondary winding for starting only; the capacitor-start version provides higher starting torque. The secondary winding uses a much smaller diameter wire energized for a limited time without overheating and automatically disconnected after start-up by a centrifugal switch. In PSC and CSCR motors, the secondary winding continues operating when the motor is running. The capacitor in series with this winding shifts the phase of the input voltage approximately 90°, so the two windings together create a rotating magnetic field. The benefits achieved by PSC and CSCR motors are the suppression of torque pulsations and the improved use of both the windings and the iron in the motor. These benefits increase the efficiency and the power factor of the motor, but at an added cost associated with the capacitor.

Single-phase motors in a two-digit NEMA frame size range from 1/4 horsepower to one horsepower and are available in two-, four-, or six-pole configurations. A four-pole configuration is the most common.

2.3 ENERGY EFFICIENCY: BASIC CONSIDERATIONS

The application of a motor to do work creates energy losses that are both external and internal to the motor. Losses that are external to the motor are influenced by the power factor of the motor. The power factor is the ratio of real power to apparent power, and ranges from zero to one. The real power (measured in watts) is used to create the useful work (and waste heat) of the motor. Reactive power (measured in volt-amps reactive) is used to create the magnetic field needed for the motor to operate, but it does not contribute to the mechanical power generated by the motor.

Internal energy losses are usually categorized as conductive, magnetic, mechanical, and stray. All of these energy losses appear as heat in the motor. Losses are strongly dependent on design and quality control of motor components.

The conventional methods for reducing losses include increasing the amount of active material (e.g., the diameter of wire conductors); substituting a higher grade of steel for the magnetic components; improving the mechanical components and design (winding, bearings, and fan); and improving the quality control of components and assembly. These methods may increase either the motor cost or size if no other changes in the motor are made.

The precise impacts on motor cost and efficiency will depend on how the designer makes tradeoffs between added performance from improved materials or design, and maintenance of the motor performance. A designer cannot ignore interaction among different motor losses in the process of optimizing. The I^2R (the expression of heat loss in watts where I is measured current and R is resistance) of the rotor is a key loss, as are windage, friction, and stray losses. Options that may reduce the stray loss can increase the core loss, while those that can reduce the windage loss may increase the I^2R loss.

Often a measure that enhances efficiency improves motor performance such that other cost-saving changes can be made to offset the cost of the efficiency improvement. An example of this is the use of more-expensive, high-permeability steel in place of iron. This leads to higher efficiency, smaller motor size, and improved torque, and also allows the volume of copper used in the motor to be reduced while maintaining performance.

Various component additions to a single-phase motor are known to improve the efficiency while increasing the cost and usually changing the motor's dimensions. Adding an auxiliary winding with a capacitor, adding an auxiliary winding with a starting capacitor and switch, or adding an auxiliary winding with starting capacitor, switch, and running capacitor to a single-phase motor can reduce energy losses, increase torque, and improve the power factor. The additional winding may be continuously energized as in the CSCR motor, or disconnected with a centrifugal switch as is often done in the CSIR motor. The CSCR motor has a switch added in series with the starting capacitor and adds a second running capacitor in parallel to the starting capacitor that is not switched out of the circuit after starting. The auxiliary winding and running capacitor of the CSCR motor contribute to motor output, allowing it to approach the efficiency of a polyphase motor.

CHAPTER 3. THE MARKET FOR CONSIDERED SMALL MOTORS

For its determination analysis, the Department examined five aspects of the market structure of considered small motors. The first key piece of information for the Department's analysis is the size of the market including estimates of current shipments and estimates of long term shipment trends. Second, the Department examined the relative market shares of different small motors with different characteristics and features. Third, the Department reviewed the range of existing motor efficiencies in the market. Fourth, the Department investigated the market structure in terms of how considered electric motors are distributed and the proportion of motors used in different applications. And fifth, the Department examined how motor prices are affected by the distribution channel employed.

3.1 ANNUAL SHIPMENTS

The historic trend in annual shipments of considered small motors is uncertain. Data from the U.S. Census Bureau[a] show little growth in the 1990s, but these data only include motors produced in the U.S.[1]

NEMA provided confidential data on two-digit-frame-size, fractional-horsepower motor sales to domestic customers by NEMA manufacturers, covering the period from 1971 to 2001. These data, after interpolation, show an average annual growth rate of 1.5 percent. The three-phase and capacitor-start motors DOE is analyzing make up only around 20 percent of the motors covered by these data.

A joint NEMA/SMMA survey in 2000 estimated U.S. sales of CSIR and polyphase motors at 5.4 and 1.3 million, respectively. CSIR motors accounted for approximately 95 percent of total shipments of capacitor-start motors.

3.2 FEATURES OF CONSIDERED SMALL MOTORS

Figures 3.1 and 3.2 show the year-2000 market shares of considered small motors with different basic features (according to the NEMA/SMMA survey). Open motors account for 93 percent of total CSIR shipments. The most important size categories (with roughly equal shares) are 1/3, 1/2, and 3/4 horsepower. The average size is 1/2 horsepower. Four-pole motors account for a somewhat higher share than two- and six-pole motors.[b]

For polyphase motors, enclosed motors account for two-thirds of total shipments, reflecting the greater use of such motors in industrial environments. The largest sales categories are 3/4 and one horsepower. The average size is one horsepower. Four-pole motors account for two-thirds of the total.

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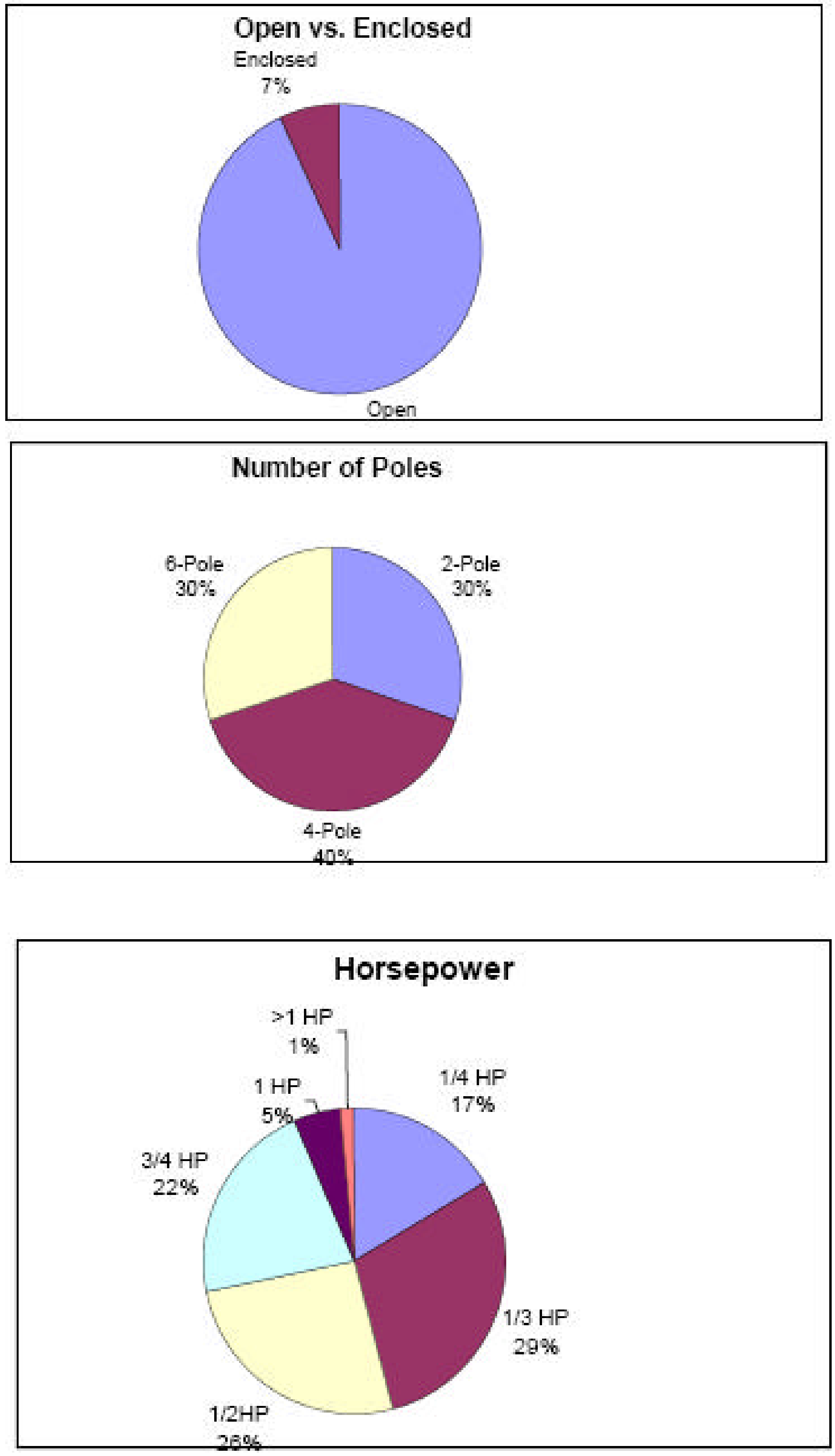
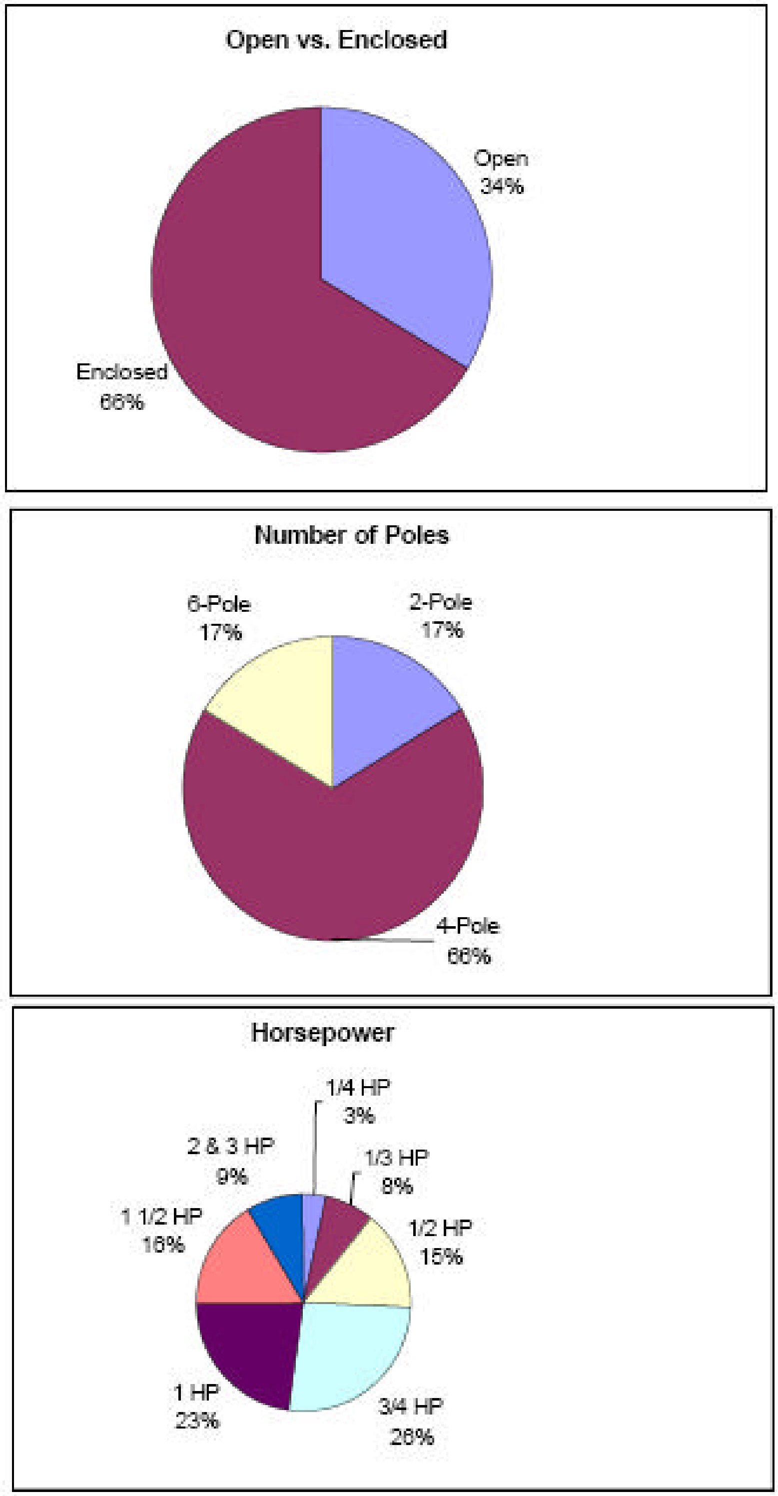
[a] The Department has included all single-phase motors, one horsepower and over, with capacitor-start motors.
[b] The shares of two- and six-pole motors are estimated values, as complete data were lacking.



Source: NEMA/SMMA survey

Figure 3.1 Capacitor-Start, Induction-Run Motors – Shipments in 2000



Source: NEMA/SMMA survey

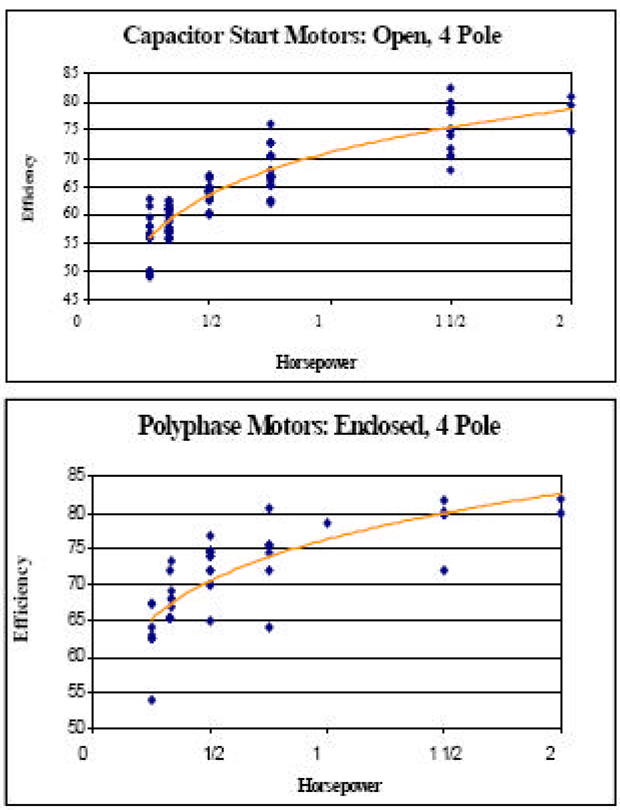
Figure 3.2 Small Polyphase Motors – Shipments in 2000

3.3 RANGE OF ENERGY EFFICIENCIES

The Department collected data from manufacturers' catalogs on the listed nominal, full-load efficiency and other features of more than 700 different models.[2] While these data provide an approximate picture of the spread of efficiencies on the market, two caveats are necessary. First, the reported efficiencies are not precisely comparable among different manufacturers, since they are not all based on the same test procedure. Second, many of the models likely have a low sales volume; thus, the spread of available model data does not portray any information about relative shipments of models.

Figure 3.3 shows the full-load efficiency versus the nominal horsepower of a sample of capacitor-start and three-phase motors available in the market in the year 2000. Generally speaking, larger motors have a higher efficiency than smaller motors in a given class. For open, four-pole, capacitor-start motors, the efficiency range is greater for 3/4 horsepower motors than for 1/3 and 1/2 horsepower motors. Some of the highest-efficiency motors larger than one horsepower are CSCR motors. For three-phase motors, there is also a significant range in efficiency.

The range of efficiencies for a given type and size is likely due in part to different methods of testing among the manufacturers, as well as differences in specific features.



Source: A.D. Little (2001)

Figure 3.3 Listed Efficiency (full load) of Small Motor Models

3.4 MARKET STRUCTURE

The Department estimates the distribution channels for considered small motors as follows:

1. Motor manufacturers ? original equipment manufacturers (OEMs) 40 percent
2. Motor manufacturers ? distributors ? OEMs 25 percent
3. Motor manufacturers ? distributors ? end users 35 percent

The motors in the last category are motors sold to end users as replacements or spares.

A high percentage of considered small motors sold in the U.S. are domestically manufactured. In addition to imported stand-alone motors, some considered small motors are imported as components of equipment built in other countries. The magnitude of such imports is difficult to determine.

Table 3.1 lists the manufacturers that produce most of the considered small motors sold in the U.S.

Table 3.1 Leading Manufacturers of Considered Small Motors Sold in the U.S.

Manufacturer	**Brand**
A.O. Smith	A.O. Smith, MagneTek,
Baldor Electric	Baldor Electric Co.
Emerson Motors	Emerson, U.S. Motors
General Electric	GE Motors
Regal-Beloit	Lincoln Motors, Marathon Electric
Rockwell Automation	Reliance Electric
TECO Electric and Machinery Co. Ltd.	TECO, TECO-Westinghouse Motor Company
Toshiba International Corporation	Toshiba International Corporation
WEG Electric Motor Corp.	WEG

There are dozens of OEMs that incorporate considered small motors in industrial, agricultural, and commercial equipment. These range in size from large to small companies.

The users of equipment containing considered small motors primarily consist of firms that have the applications listed in Table 3.2. The large diversity of applications poses challenges with respect to accurately characterizing typical motor usage patterns. To determine how considered small motors are used, the Department reviewed trade literature and conducted interviews with manufacturers that produce the equipment into which small motors are incorporated.[3] See Appendix A for a more detailed description of how the Department gathered its information for this product.

The estimated typical annual hours of use range from 800 hours for air and gas compressors to 5000 hours for industrial/commercial fans and blowers. Many of the values are in the 2000–3000 range.

Table 3.2 Average Use Characteristics for General Purpose Small Motors by Type of Application

Application	Hours/year	Motor loading (% of rated)
Farm machinery	1000	70%
Conveyors	3000	50%
Machine tools	2000	60%
Textile machinery	3000	70%
Woodworking machinery	2000	35%
Food machinery	3000	60%
Pumps and pumping equipment	3000	65%
Air and gas compressors	800	85%
Industrial and commercial fans and blowers	5000	80%
Packaging machinery	3000	60%
General industrial machinery	2000	n/a
Commercial laundry machinery	2000	60%
Commercial and Industrial HVAC/refrigeration equipment	2500	60%
Service industry machinery	1500	n/a

Source: Easton Consultants (2001)

The Department also investigated typical motor-loading practices. The motor loading is commonly in the 60–70 percent range, although it is higher in two cases, air and gas compressors and industrial/commercial fans and blowers, and lower in two cases, conveyors and woodworking machinery.

To assess the relative importance of different application categories, the Department estimated the magnitude of annual shipments of considered small motors to each group, shown in Table 3.3 (see Appendix B for more discussion of its method). Motors used in pumps and pumping equipment and in commercial and industrial HVAC/refrigeration equipment each account for approximately 30 percent of the total shipments for capacitor-start motors. No other category accounts for more than 10 percent. Motors used in pumps and pumping equipment are the largest category for polyphase motors, followed by commercial and industrial HVAC/refrigeration equipment and conveyors.

Table 3.3 Estimated Annual Shipments of General Purpose Small Motors by Type of Application

Application	Cap. Start		Polyphase	
	'000	%	'000	%
Farm machinery	457	10.9	33	3.0
Conveyors	497	11.8	207	18.8
Machine tools	81	1.9	81	7.3
Textile machinery	18	0.4	13	1.2
Woodworking machinery	101	2.4	34	3.1
Food machinery	90	2.1	90	8.2
Pumps and pumping equipment	1723	41.1	364	33.0
Air and gas compressors	338	8.1	101	9.2
Industrial and commercial fans and blowers	248	5.9	62	5.6
Packaging machinery	12	0.3	11	1.0
General industrial machinery	101	2.4	38	3.4
Commercial laundry machinery	52	1.2	4.5	0.4
Commercial and Industrial HVAC/refrigeration equipment	354	8.4	47.8	4.3
Service industry machinery	125	3.0	16	1.5
TOTAL	4197	100	1102	100

Source: Easton Consultants (2001), adjusted by DOE in 2006 to account for motors in newly covered products.

3.5 MOTOR PURCHASING

An end-user will almost always replace a worn-out motor with the same model, which means that the motor purchase decision is effectively made by the OEMs, and not by the end-users who use the motors and pay for the electricity to operate them. The price paid for a motor depends on the type of purchaser and the volume purchased. The Department's research indicates typical ranges as follows:

Table 3.4 Motor Purchases

Channel	Purchase price (% of list)
Motor Manufacturers ? OEMs	37-40
Motor Mfrs ? Distributors ? OEMs	46-48
Motor Mfrs ? Distributors ? End Users	65-75

In its interviews with OEMs, the Department inquired about their attitudes toward motor energy efficiency. A summary of the views of the OEM representatives follows:

1. Efficiency is not a high priority in selection of motors for most of the equipment studied. The OEMs stated that they have not given much attention to motor efficiency in this size range primarily because their customers do not request more-efficient motors, and are more concerned with first cost than with small reductions in operating cost.

2. The OEMs stated that there was more interest in energy efficiency in select industrial categories—conveyors, food products machinery, industrial pumps, and packaging equipment—than others. They indicated that their customers expressed more interest in energy efficiency where hours of operation are longer and the end-user customer is a more sophisticated, cost-sensitive operator. These categories in total represented about 40 percent of two-digit motors. (The response from the HVAC category was mixed, with some OEMs quite interested in greater efficiency, and others not.)

3. Several OEMs interviewed expressed interest in total-motor-system efficiency, particularly adjustable-speed drives. There is wide recognition that energy can be saved with the installation of adjustable-speed drives and other devices to control motor systems, particularly in HVAC fans and industrial pumps.

Many of the product designers noted that there are few premium-efficient, two-digit motors available. They stated that, even if an OEM wanted to use a more efficient motor, it would be difficult because motor manufacturers offer very few premium-efficient motors in these frame sizes. In the case of several manufacturers of single-phase motors, the CSCR motors are designated “premium efficient” in contrast to CSIR motors. However, the former are not always physically interchangeable with a CSIR motor.

REFERENCES

1. U.S. Census Bureau, Current Industrial Reports, Motors and Generators – MA335H.

2. Arthur D. Little, 2001. Small motor database (prepared for this study).

3. Easton Consultants, 2001. Analysis of considered motors use by principal machinery categories (prepared for this study).

CHAPTER 4. ENGINEERING ANALYSIS OF DESIGN OPTIONS TO IMPROVE EFFICIENCY OF CONSIDERED SMALL MOTORS

The engineering analysis provides the relationship between motor cost and efficiency that the Department used as a key input to its analysis of economic justification. The Department employed two methods for obtaining this cost-efficiency data. The first method was to retain an independent expert to estimate the cost of modifying baseline motors that are currently available in the market to versions that have higher efficiency designs. The second method was to share the preliminary cost-efficiency analysis with manufacturers and to solicit similar, aggregate cost-efficiency data from a committee of manufacturer representatives. The two cost-efficiency data collections provide significantly different sets of cost-efficiency data.

Because of the small number of shipments for the CSCR motors relative to CSIR motors, the Department analyzed only CSIR designs in its engineering analysis and refers to the two product classes collectively as "capacitor-start" motors.

4.1 APPROACH

The Department used a design-option approach to estimate cost-efficiency curves for considered small motors. In this approach, the Department selects a baseline design that is then modified by different design options that increase motor efficiency. The design options are sorted from least expensive to most expensive, and the sorted list of designs and corresponding production costs provide a cost-efficiency relationship. The Department used an independent expert to estimate one set of cost-efficiency data, and solicited another set of cost-efficiency data from a committee of motor manufacturers.

The Department began its design option selection by first considering which types of design changes would provide the most practical and cost-effective efficiency improvements. The most practical ways to adjust motor performance to achieve increased efficiency for the considered small motors are: (1) change the grade of electrical steel; (2) change the stack length; and (3) change the flux density by adjusting the effective turns or changing the thickness of the steel. The Department estimated the first two design options to be the most cost-effective for increasing motor efficiency, and therefore examined only the first two design-option types in this determination analysis. The justification for this approach is that if the analysis on a subset of the design options shows that energy efficiency can be increased cost-effectively, then an analysis on the complete set of design options would result in the same conclusion.

As shown in Table 4.1, the characteristics of the steel for the steel-grade-improvement design options covered approximately the same range of steel-grade characteristics for the DOE analysis and the manufacturers' analysis. Both analyses included both cold-rolled and semi-processed electrical steel. The DOE analysis examined steel thicknesses ranging from 0.031 inch to 0.019 inch, while the manufacturers' analysis examined a steel thickness range from 0.031 inch to 0.018 inch.

For the stack-length change design options, the Department considered incremental increases of 0.25 inch in stack length in its sample motors. The Department's independent expert used motor design software combined with sample motor test data to estimate the impacts of the stack length changes on stator and rotor I^2R losses, steel losses, friction and windage losses, and stray losses to estimate the efficiencies of the longer stack-length motors.

The Department presented its preliminary results regarding the efficiency improvements that would result from steel-grade and stack-length changes before the manufacturers provided their cost-efficiency estimates.

Table 4.1 Electrical Steel Options Considered

Grade	**Type**	**Maximum Loss** (watts/lb @15kg, 60 hz)	**Thickness** (inch)
DOE Analysis			
Grade A	Cold rolled	4.51	0.031
Grade B	Cold rolled	4.15	0.031
Grade A+	Cold rolled	4.04	0.025
Grade B+	Cold rolled	2.78	0.022
M47	Semi-processed electrical*	1.53	0.019
Manufacturers' Analysis			
Grade 1	Cold rolled		0.026-0.031
Grade 2	Cold rolled		0.022-0.025
Grade 3	Semi-processed electrical*		0.018-0.022

* Semi-processed steel with full anneal after punching

4.1.1 The Department's Cost-Efficiency Analysis

The Department developed cost-efficiency data by retaining an independent expert to test a set of baseline or prototype motors, and then analyzed the impact on cost and efficiency of steel-grade changes and stack-length changes to these baseline designs.

The Department used two prototype motors each for its capacitor-start motor analysis and its polyphase motor analysis. For the capacitor start analysis, the Department's expert selected Dayton motors with model numbers 4K856 and 6K965 as the prototype designs and assigned the results corresponding to these two baseline motors as "DOE #4K" and "DOE #6K." These two motors have NEMA frame sizes 56 and 48, respectively, and so have different cost-efficiency characteristics.

For polyphase motors, the Department's expert used two ½-horsepower Dayton motors and one one-horsepower motor with model numbers 3N641, 2N103, and 3N102. The Department refers to the data derived from these three baseline motors as "polyphase DOE #3N, ½ horsepower," "polyphase DOE #2N, ½ horsepower," and "polyphase DOE #3N, 1 horsepower," respectively.

The Department's analysis of the cost impacts of efficiency improvements only considered the increased cost of improved electrical steel, copper winding, and aluminum rotor bar/end ring. The Department calculated these material costs based on typical costs when purchased in volume. No other materials are normally affected by the design changes considered. The Department did not consider labor and burden because these cost components are small and are not expected to vary substantially with higher efficiency. It also did not consider the impact on set-up time and the introduction of new part numbers, because such costs are uncertain and are also likely to be small.

In each case, DOE gave the baseline motor a "per-unit" (PU) cost of one. All changes to the motor cost are related to the PU cost of one. For example, if a change in electrical steel represented a 10-percent change in the total motor cost, the PU number would be 1.10 for the new design.

4.1.2 Cost-Efficiency Data Submitted by Motor Manufacturers

In addition to the analysis described above, the Department asked a working group of motor manufacturers established by NEMA and SMMA to provide comparable data. The results for steel-grade changes, provided by four manufacturers, show considerable variability in both baseline motor efficiency and the incremental cost of efficiency improvements (Figure 4.1). Each manufacturer selected a typical motor to use as the "baseline motor." The Department believes that each manufacturer used somewhat different methods and assumptions concerning efficiency and cost changes. Furthermore, the precise steel grades considered varied, so the data are presented in terms of Grades 1, 2, and 3 (see Table 4.1 above).

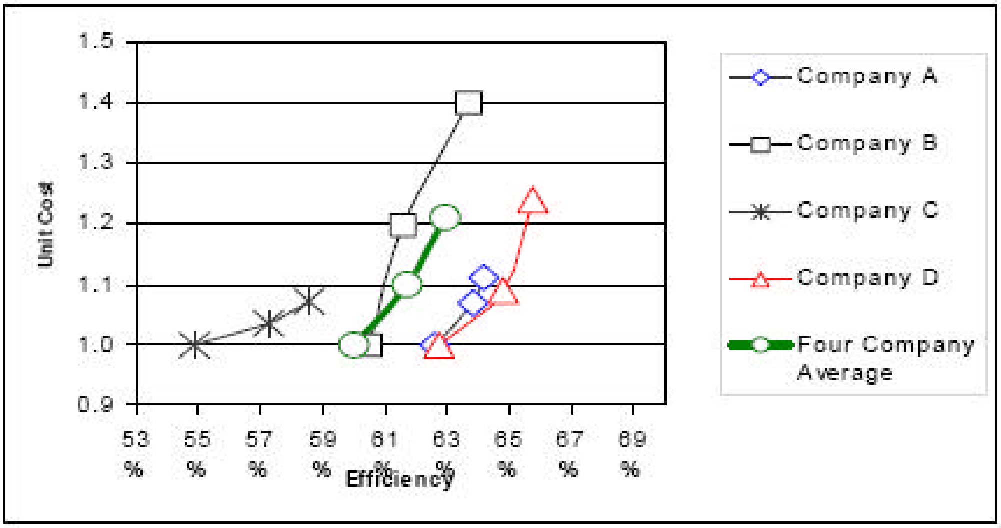


Figure 4.1 Increase in Efficiency and Cost from Steel-grade Change, Capacitor- Start, ½ horsepower, NEMA/SMMA data*
***Cost for Companies A, B, and D includes capital for new production tooling**

For steel-grade options, the NEMA/SMMA data in the tables below refer to the average values of the four submissions. In calculating the average cost-efficiency relationship, the Department averaged the PU values and efficiencies of the four submissions for each grade (i.e. "Grade 1", "Grade 2," and "Grade 3"). For stack-length change options, the NEMA/SMMA working group provided data that it considered most typical.

4.2 EFFICIENCY AND COST IMPACTS OF DESIGN OPTIONS

The tables below present the results of the analyses of steel-grade and stack-length change design options. All calculations assume operation at 70 percent of the rated load.

4.2.1 Capacitor-Start Motors: Steel-grade Options

The Department presents engineering data for steel-grade design options in the capacitor-start motors in Tables 4.2 to 4.4. The Department examined efficiency improvements for 56 frame and 48 frame motors which the Department refers to as 4K and 6K, respectively. The NEMA average data show much less efficiency gain than does the DOE analysis.

Table 4.2 Capacitor-start DOE #4K, ½ horsepower, 4-pole, ODP

	Grade A	Grade B	Grade B+	M47
P.U. Cost	1.00	1.03	1.08	1.25
Input (Watts)	492	462	447	438
Output (Watts)	265	265	265	265
Loss (Watts)	227	197	182	173
Efficiency	53.9%	57.4%	59.3%	60.5%

Table 4.3 Capacitor-start DOE #6K, ½ horsepower, 4-pole, ODP

	Grade A	Grade B	Grade B+	M47
P.U. Cost	1.00	1.03	1.10	1.25
Input (Watts)	417	399	391	378
Output (Watts)	261	261	261	261
Loss (Watts)	156	138	130	117
Efficiency	62.6%	65.4%	66.8%	69.0%

Table 4.4 Capacitor-start NEMA, ½ horsepower, 4-pole, ODP

	Grade 1	Grade 2	Grade 3
P.U. Cost	1.00	1.10	1.21
Input (Watts)	435	423	415
Efficiency	60.0%	61.7%	62.9%

4.2.2 Capacitor-Start Motors: Stack-change Options

The Department presents engineering data for stack-length change design options in the capacitor-start motors in Tables 4.5 to 4.7. In the Department's analysis, the stack-length change options yield less efficiency gain (for the DOE 6K) than do the steel-grade options discussed above. The NEMA/SMMA analysis shows somewhat greater efficiency gain from stack change than does DOE's analysis of the 6K motor, and a greater efficiency improvement for stack-length change than the NEMA/SMMA analysis for steel-grade improvement.

Table 4.5 Capacitor-start DOE #4K, ½ horsepower, 4-pole, ODP

	Base	Plus stack	Plus 2 stack	Plus 3 stack
P.U. Cost	1.00	1.09	1.19	1.29
Input (Watts)	492	458	441	429
Output	265	266	266	266
Loss (Watts)	227	192	175	163
Efficiency	53.9%	58.1%	60.3%	62.0%

Table 4.6 Capacitor-start DOE #6K, ½ horsepower, 4-pole, ODP

	Base	Plus stack	Plus 2 stack	Plus 3 stack
P.U. Cost	1.00	1.07	1.15	1.22
Input (Watts)	417	411	405	401
Output (Watts)	261	261	261	261
Loss (Watts)	156	150	144	140
Efficiency	62.6%	63.5%	64.4%	65.1%

Table 4.7 Capacitor-start NEMA, ½ horsepower, 4-pole, ODP

	Base	Plus stack	Plus 2 stack	Plus 3 stack
P.U. Cost	1.00	1.10	1.20	1.30
Input (Watts)	421	406	398	392
Efficiency	62.0%	64.3%	65.5%	66.5%

4.2.3 Polyphase Motors: Steel-grade Options

The Department presents engineering data for steel-grade design options in the polyphase motors in Tables 4.8 to 4.11. DOE analyzed efficiency improvements for three baseline motors: Dayton motors with model numbers 3N641, 2N103, and 3N102. The Department refers to the data derived from these three baseline motors as "polyphase DOE #3N, ½ horsepower," "polyphase DOE #2N, ½ horsepower," and "polyphase DOE #3N, 1 horsepower" respectively. In DOE's analyses, the lowest-loss option (M47) yields an efficiency gain of approximately 5.0 to 5.5 percentage points. The NEMA average shows an increase of four percentage points from the baseline motor to Grade 3.

Table 4.8 Polyphase DOE #3N, ½ horsepower, 4-pole, ODP

	Grade A	Grade B	Grade B+	M47
P.U. Cost	1.00	1.03	1.07	1.15
Input (Watts)	361	352	347	338
Output (Watts)	267	267	267	267
Loss (Watts)	94	85	80	71
Efficiency	74.0%	75.8%	76.9%	79.0%

Table 4.9 Polyphase DOE #2N, ½ horsepower, 4-pole, ODP

	Grade A	Grade B	Grade B+	M47
P.U. Cost	0.93	0.96	1.00	1.14
Input (Watts)	381	368	363	353
Output (Watts)	266	266	267	267
Loss (Watts)	115	102	96	86
Efficiency	70.1%	72.3%	73.5%	75.6%

Table 4.10 Polyphase NEMA, ½ horsepower, 4-pole, ODP

	Grade 1	Grade 2	Grade 3
P.U. Cost	1.00	1.10	1.20
Input (Watts)	383	369	362
Efficiency	68.1	70.7	72.1

Table 4.11 Polyphase DOE #3N, One horsepower, 4-pole, ODP

	Grade A+	Grade B+	M47
P.U. Cost	1.0	1.04	1.20
Input (Watts)	699	682	658
Output (Watts)	534	534	534
Loss (Watts)	165	148	124
Efficiency	76.4%	78.3%	81.2%

Note: Grade B yields same efficiency as Grade A+

4.2.4 Polyphase Motors: Stack-change Options

The Department presents engineering data for stack-change design options in the polyphase motors in Tables 4.12 to 4.15. The efficiency gain from an increase in stack length is quite dependent on the baseline motor design. For the DOE #3N, ½ horsepower motor, the efficiency increase is only 1.5 percent from base to plus 3 stack, while for the DOE #2N, ½ horsepower motor, the improvement is 4.7 percent. The NEMA/SMMA data for a ½ horsepower motor shows a relatively small improvement from stack length changes of only 1.9 percent.

Table 4.12 Polyphase DOE #3N, ½ horsepower, 4-pole, ODP

	Base	Plus stack	Plus 2 stack	Plus 3 stack
P.U. Cost	1.00	1.10	1.17	1.23
Input (Watts)	361	359	354	355
Output (Watts)	267	268	266	268
Loss (Watts)	94	91	88	87
Efficiency	74.0%	74.7%	75.1%	75.5%

Table 4.13 Polyphase DOE #2N, ½ horsepower, 4-pole, ODP

	Base	Plus stack	Plus 2 stack	Plus 3 stack
P.U. Cost	1.00	1.08	1.23	1.37
Input (Watts)	363	358	347	340
Output (Watts)	267	267	266	266
Loss (Watts)	96	91	88	87
Efficiency	73.5%	74.6%	76.6%	78.2%

Table 4.14 Polyphase NEMA, ½ horsepower, 4-pole, ODP

	Base	Plus stack	Plus 2 stack	Plus 3 stack
P.U. Cost	1.00	1.08	1.16	1.24
Input (Watts)	361	357	353	352
Efficiency	72.2%	73.1%	73.9%	74.1%

Table 4.15 Polyphase DOE #3N, One horsepower, 4-pole, ODP

	Base	Plus stack	Plus 2 stack	Plus 3 stack
P.U. Cost	1.00	1.06	1.18	1.24
Input (Watts)	699	692	677	674
Output (Watts)	534	534	534	534
Loss (Watts)	165	158	143	140
Efficiency	76.4%	77.2%	78.9%	79.2%

CHAPTER 5. LIFE-CYCLE COST ANALYSIS OF DESIGN OPTIONS TO IMPROVE EFFICIENCY OF SMALL MOTORS

5.1 METHOD AND DATA

To assess the LCC to end users of designs that improve motor efficiency, the Department conducted an analysis that compares the incremental first cost to the value of electricity savings. In particular, the LCC analysis compares the incremental first cost to the discounted value of electricity savings over the life of the motor. The simple payback period analysis calculates the amount of time required for the electricity savings to equal the incremental first cost, assuming the electricity savings in future years is constant and equal to that in the first year.

The analysis requires several inputs:

1. Typical use in terms of hours and loading;
2. Typical price for the baseline motors (so the percentage change in per unit cost can be expressed in dollar terms);
3. Typical motor lifetime;
4. Electricity price; and
5. Discount rate (to convert future operating cost savings into present value terms).

The Department discusses these variables below.

5.1.1 Motor Use

The estimates of average annual hours of use, loading, and shipments for each application category (see Chapter 3) yield shipments-weighted-average values as follows:

- Annual hours of use: 2500 (for both capacitor-start and polyphase)
- Average loading (percent of rating): 70%

5.1.2 Price for the Motors

The Department calculated average purchase prices for the prototype motors using the following assumptions:

Table 5.1 Calculated Average Purchase Prices for Prototype Motors

Channel	Distribution of sales (%)	Purchase price (% of list)
Motor Manufacturers ? OEMs	40	38
Motor Mfrs ? Distributors ? OEMs	25	47
Motor Mfrs ? Distributors ? End Users	35	70

The resulting weighted-average price is 51 percent of list. The Department applied this value for each motor analyzed. For the motors it analyzed, the Department used model-specific list prices given in the 2001/02 Grainger catalog.[1] For the motors analyzed by the NEMA/SMMA working group, the Department estimated list prices based on representative motors in the Grainger catalog.

The Department assumes that the full incremental cost of higher-efficiency motors is passed on to equipment buyers by the OEMs without additional markup. This assumption affects 65 percent of the sales as shown in the two rows with OEM end-users in Table 5.1 above.

Also, for each product class, the Department chose the cost-efficiency data that corresponded to the baseline motor that is most representative of the product class (today). For the Department's capacitor start analysis, the Department selected the "DOE 6K" data, while for the Department's polyphase motor analysis, the Department used the "polyphase DOE #3N, one horsepower" data.

5.1.3 Motor Lifetime

The typical lifetime of small motors in the field is not well understood. Studies by one manufacturer show that small motors have an "L10" life (defined as the point where 10 percent of test population has failed) under typical operating conditions of around 25,000 hours ("typical" assumes no start/stop or excessive vibration, 75° C bearing temperatures, normal mineral-oil-based bearing lubricants, and regular-sized lubricant reservoirs). For an average use of 2500 hours per year, that would yield a ten-year L10 life. The key input parameter for the Department's analysis is the average lifetime. Because only 10% of motors have failed at the L10 life, the L10 life underestimates the average lifetime which is likely to be one to several years longer.

The life of a motor depends on a variety of factors in the service conditions of the application. These include environment (largely temperature), loading of the motor, and speed of rotation. The studies cited above have shown that bearing failure is by far the most common cause of motor failure. In turn, the main reason for bearing failure is failure of the lubricant, mainly due to heat generation and consequent lubricant degradation.

The three-phase integral motor in mostly three-digit sizes has an average life of 11 or 12 years. While most integral-horsepower motors have grease fittings on the bearings (per industry standards), all two-digit motors and fractional horsepower motors have permanently sealed bearings. This means the life of the two-digit motor is no longer than the breakdown point of the lubricant and, as a result, the life of the two-digit motor will likely be shorter than that of the three-digit motor. Motor-industry experts consulted by the Department suggest that the average life for two-digit motors is at most 10 years, depending on the usage and physical environment.

The Department received some input on motor lifetime from OEMs. A complicating factor is that, in some cases, the potential lifetime of the motor may be longer than that of the equipment. Thus, the actual motor lifetime is limited by the lifetime of the equipment. Similarly, replacement motors, which account for about one-third of the market for the considered motors, may have a shorter average lifetime than motors installed in original equipment if the equipment fails sooner than anticipated.

The NEMA/SMMA small-motor-efficiency task force agreed with an estimated average life of 5 to 10 years for fractional horsepower motors, with the average being closer to 10 years for three-phase and closer to 5 years for single-phase motors.

Based on the above considerations, the Department elected to use a mean lifetime of seven years for capacitor-start motors and nine years for polyphase motors, as the approximate values that are most consistent with available motor lifetime information.

5.1.4 Electricity Price

The Department determined the relevant price of electricity based on the type of entities that purchase and own considered small motors. The Department estimates that, based on the market research done by Easton Consultants, approximately three-fourths of capacitor-start motors are used by utility customers on a commercial tariff, while most users of small, polyphase motors are on an industrial tariff.[2] The Department based commercial and industrial electricity prices on the average of the 2010 and 2020 forecasts from the Energy Information Administration's Annual Energy Outlook 2006.[3] For capacitor-start motors, the Department derived an average price, giving a 0.75 weighting to the commercial price. For polyphase motors, the Department increased the industrial price of electricity by five percent to reflect its belief that use of these motors is weighted toward smaller facilities, which would pay a higher tariff than large, industrial customers.

Table 5.2 Electricity Prices

Motor Type	Price used in the analysis (cents/kWh*)
Capacitor-start	7.2
Polyphase	5.6

*Cents in year 2005 values

5.1.5 Discount Rate

The discount rate is the rate at which future expenditures are discounted to estimate their present value. The Department derived the LCC discount rates for considered small motors from data it collected for the LCC discount rate estimates in the distribution transformer rulemaking. Following financial theory, the cost of capital can be interpreted in three ways: 1) it is the discount rate that should be used to reduce the future value of cash flows to be derived from a typical company project or investment; 2) it is the economic cost to the firm of attracting and retaining capital in a competitive environment; and 3) it is the return that investors require from their investment in a firm's debt or equity. The Department primarily used the first interpretation. Most companies use both debt and equity capital to fund investments; for most companies, therefore, the cost of capital is the weighted average of the cost to the firm of equity and debt financing.

Appendix C presents the details of the Department's estimates of the cost of capital for commercial and industrial companies. The Department estimates the real (i.e., inflation-adjusted) cost of capital for commercial companies as 7.3 percent, and that of industrial companies as 7.5 percent. Because industrial companies purchase the bulk of small motors, the Department used the 7.5 percent discount rate for its LCC analysis.

5.2 RESULTS FOR CAPACITOR-START, INDUCTION-RUN MOTOR DESIGN OPTIONS

The tables and figures below present key results of the LCC and payback period analyses. The Department only presents results for the most typical motors. Specifically, for the Department's engineering data, the Department selected the "DOE 6K" data for the capacitor start product class, while for the Department's polyphase motor analysis, the Department used the "polyphase DOE #3N, one horsepower" data. Note that the baseline motors are different in the DOE and NEMA/SMMA analyses.

In the DOE analysis, the steel-grade options all have lower LCC than the baseline motor. The Department presents these results numerically in Table 5.3 and graphically in Figure 5.1. In contrast, the steel-grade results based on the NEMA/SMMA average data, presented in Table 5.4 and Figure 5.2, show essentially no change in LCC for grade 2 and then an increase in LCC for grade 3.

The DOE results in Table 5.3 and Figure 5.1 show that the stack-length options increase the LCC. The NEMA results, presented in Table 5.4 and Figure 5.2, show a slight decrease for the first stack-length option, but then an increase in LCC for the stack-change options that result in higher efficiencies.

Table 5.3 Impacts of Efficiency Improvement on Typical End User, Capacitor-Start, ½ horsepower, DOE Data*

	Steel Grade				Stack Change		
	Grade A (Base)	**Grade B**	**Grade B+**	**M47**	**Plus Stack**	**Plus 2 Stack**	**Plus 3 Stack**
Motor Price–Buyer**	$103	$106	$114	$129	$111	$119	$126
Annual Operating Cost	$75	$72	$70	$68	$74	$73	$72
Life-Cycle Cost (7.5% DR)	$501	$487	$486	$490	$502	$505	$508
Change in LCC (WRT Base)		-$14.07	-$14.47	-$11.37	$1.51	$4.05	$7.47
Percent Change in LCC		-2.8%	-2.9%	-2.3%	0.3%	0.8%	$1.5%
Payback Period (years)		1.0	2.2	3.7	6.7	7.2	7.9

*Data refer to a specific typical motor
**Based on actual motor price in Grainger catalog.

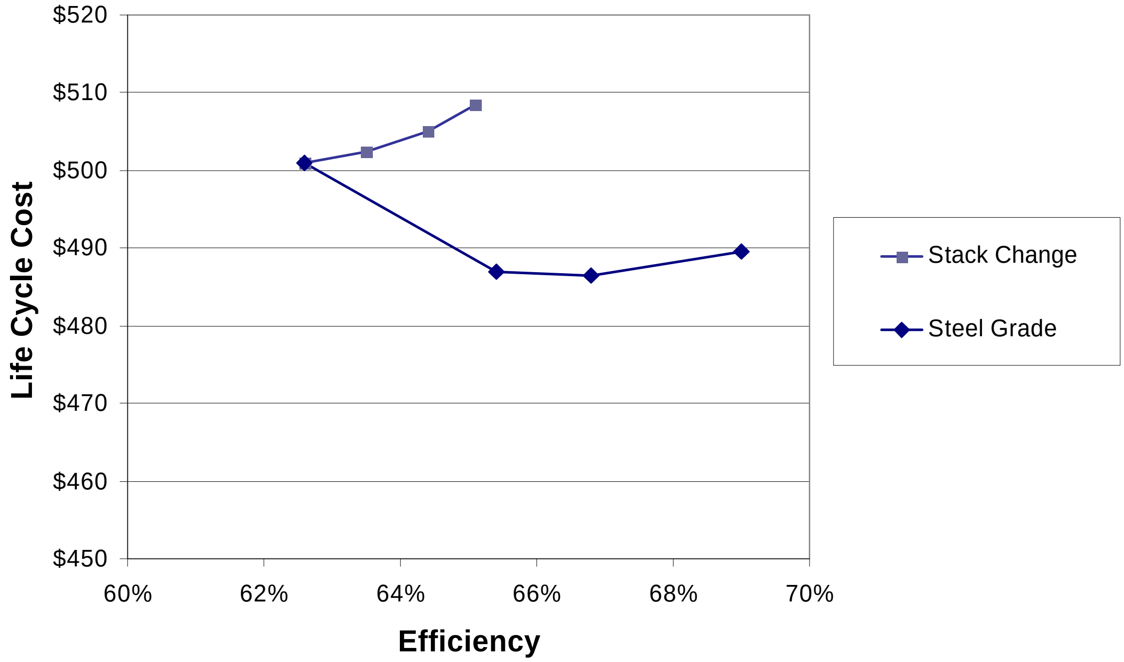


Figure 5.1 Capacitor-start ½ horsepower -- DOE Data

Table 5.4 Impacts of Efficiency Improvement on Typical End User, Capacitor-Start, ½ horsepower, NEMA/SMMA data

	Steel Grade*			**Stack Change****			
	Grade 1 (Base)	**Grade 2**	**Grade 3**	**Base**	**Plus Stack**	**Plus 2 Stack**	**Plus 3 Stack**
Motor Price—Buyer***	$117	$128	$141	$117	$128	$140	$152
Annual Operating Cost	$78	$76	$75	$76	$73	$72	$71
Life-cycle Cost (7% DR)	$532	$532	$537	$518	$516	$520	$526
Change in LCC (WRT Base)		-$0.01	$5.20		-$2.63	$1.41	$7.36
Percent Change in LCC		0.0%	1.0%		-0.5%	0.3%	1.4%
Payback Period (years)		5.3	6.7		4.3	5.6	6.7

* Data are average of four manufacturers
** Data reflect costs and performance of a typical motor
*** Estimated by DOE based on Grainger catalog prices

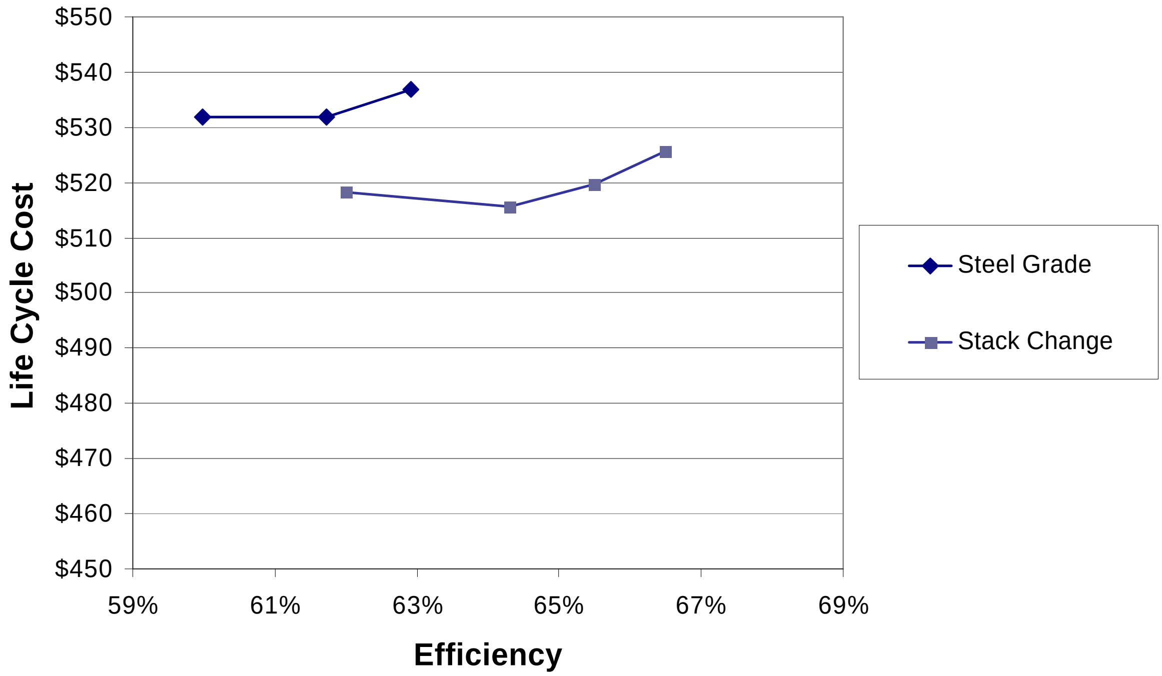


Figure 5.2 Capacitor-start ½ horsepower -- NEMA/SMMA data

In summary, for capacitor start motors, the Department's analysis shows large economically justified (from the perspective of the 'average owner') energy savings for steel-grade changes, and no economically justified potential savings from stack-length change design options. In contrast, the NEMA/SMMA data shows potentially economically justified savings for small improvements obtained from both stack-length change and steel-grade improvements.

5.3 RESULTS FOR POLYPHASE MOTOR OPTIONS

Tables 5.5 and 5.6 present key results of the LCC analysis for the most typical polyphase motors. Table 5.5 presents results based on the DOE data, and Table 5.6 presents results based on the NEMA/SMMA data. Graphical results are provided in Figures 5.3 and 5.4, respectively. Note that the baseline motors are different in the DOE and NEMA/SMMA analyses.

In the DOE analysis, the steel-grade options all have lower LCC than the baseline motor. However, the NEMA/SMMA average results show essentially equivalent results for grades 1 and 2, followed by a slight increase in LCC for grade 3. In both the DOE and NEMA/SMMA analyses, the stack-length options increase the LCC relative to the baseline motors, although the "plus stack" and "plus 2 stack" options have life-cycle costs that are only slightly higher than the baseline motor in the DOE analysis.

Table 5.5 Impacts of Efficiency Improvement on Typical End User, Polyphase One horsepower, DOE Data*

	Steel Grade			Stack Change		
	Grade A+ (Base)	**Grade B+**	**M47**	**Plus Stack**	**Plus 2 Stack**	**Plus 3 Stack**
Motor Price–Buyer**	$119	$124	$143	$126	$140	$148
Annual Operating Cost	$98	$96	$93	$97	$95	$95
Life-cycle Cost (7.5% DR)	$746	$736	$733	$747	$748	$752
Change in LCC (WRT Base)		-$10.49	-$12.98	$0.86	$1.69	$6.14
Percent Change in LCC		-1.4%	-1.7%	0.1%	0.2%	0.8%
Payback Period (years)		2.0	4.1	7.3	6.9	8.1

*Data refer to a specific typical motor
**Based on actual motor price in Grainger catalog.

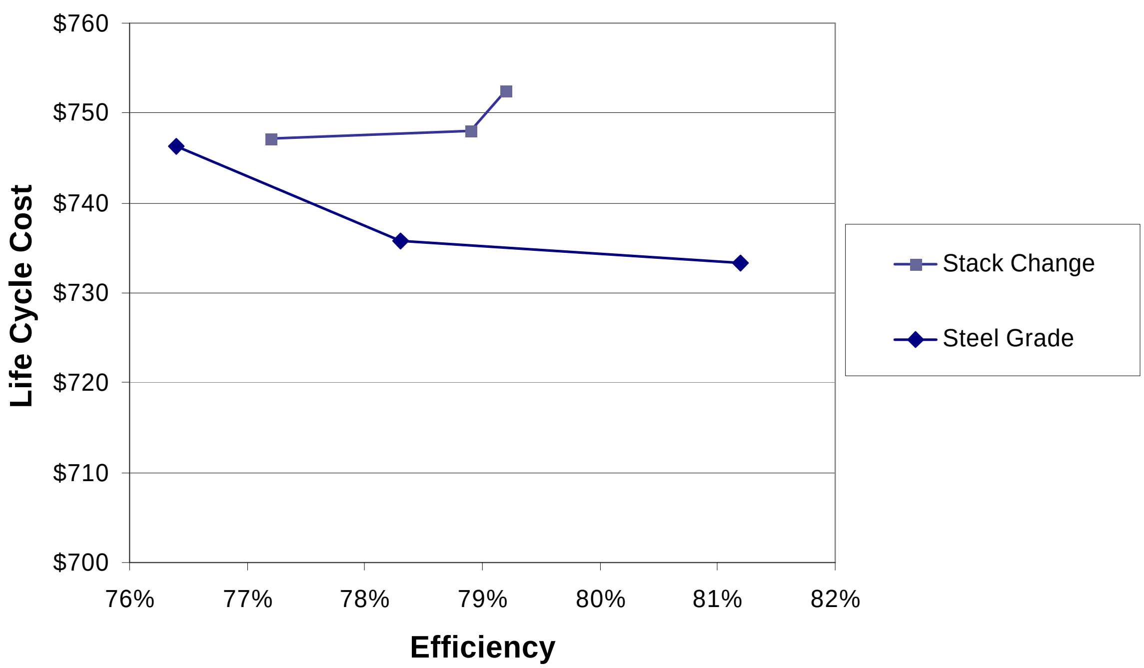


Figure 5.3 Polyphase One horsepower -- DOE Data

Table 5.6 Impacts of Efficiency Improvement on Typical End User, Polyphase ½ horsepower, NEMA/SMMA data

	Steel Grade*			Stack Change**			
	Grade 1 (Base)	Grade 2	Grade 3	Base	Plus Stack	Plus 2 Stack	Plus 3 Stack
Motor Price—Buyer***	$125	$138	$151	$126	$136	$146	$156
Annual Operating Cost	$53.9	$51.9	$50.9	$50.8	$50.2	$49.7	$49.5
Life-cycle Cost (7% DR)	$469	$469	$475	$450	$456	$463	$472
Change in LCC (WRT Base)		-$0.02	$6.02		$6.48	$12.96	$22.14
Percent Change in LCC		0.0%	1.3%		1.4%	2.9%	4.9%
Payback Period (years)		6.4	8.4		17.9	17.9	23.9

* Data are average of four manufacturers
** Data reflect costs and performance of a typical motor
*** Estimated by DOE based on Grainger catalog prices

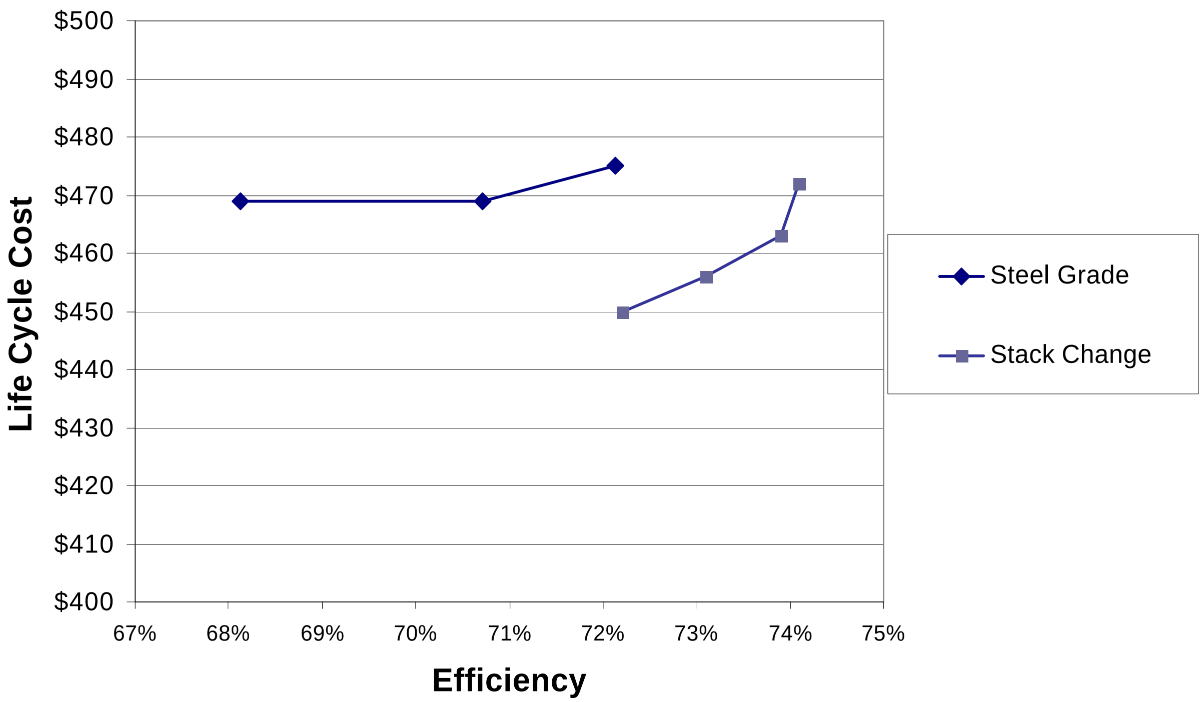


Figure 5.4 Polyphase ½ horsepower -- NEMA/SMMA data

In summary, for polyphase motors, the Department's analysis shows economically justified (from the perspective of the 'average owner') energy savings for steel-grade changes, and no economically justified potential savings from any stack-length change design options. The

NEMA/SMMA data show small economically justified savings for small improvements obtained from steel-grade improvements, and no economically justified savings for improvements obtained from stack-length changes.

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CHAPTER 6. POTENTIAL NATIONAL ENERGY AND CONSUMER IMPACTS OF ENERGY CONSERVATION STANDARDS FOR SMALL MOTORS

For this determination analysis, the Department analyzed a range of forecast scenarios and potential efficiency improvements to characterize the national impacts of a possible energy conservation standard for considered small motors. National impacts depend on the base-case motor efficiency, potential shipments growth, and the source of motor cost-efficiency data (since the Department's the NEMA/SMMA data are substantially different). For each national impact result and each cost-efficiency data source, the Department provides four results corresponding to the following forecast scenarios:

1. Low-efficiency-gain base case (1/4 precent average gain relative to year 2000), low shipments growth (1 percent per year)
2. Moderate-efficiency-gain base case (1 percent average gain relative to year 2000), high shipments growth (1 percent per year)
3. Low-efficiency-gain base case (1/4 percent average gain relative to year 2000), high shipments growth (1.5 percent per year)
4. Moderate-efficiency-gain base case (1 percent average gain relative to year 2000), high shipments growth (1.5 percent per year)

The next two sections present details of the methodology and results of the national impact estimates.

6.1 METHOD

In each product class, the Department used the characteristics of a representative motor of average size as a primary input into the estimation of national impacts:

- Capacitor-start motors 1/2 horsepower
- Polyphase motors one horsepower

The Department used the results of the DOE and manufacturers' engineering analyses (Chapter 4) to provide the cost-efficiency characteristics of the representative motor. Specifically for the Department's capacitor start analysis, the Department selected the "DOE 6K" data, while for the Department's polyphase motor analysis, the Department used the "polyphase DOE #3N, one horsepower" data. For polyphase motors, however, the Department only used the DOE results, as the manufacturers' analysis was based only on 1/2 horsepower motors which is 1/2 of the average size of motors of this product class, and thus is not representative of this product class's cost-efficiency characteristics. For each design option, the Department expresses the estimated savings relative to the base case.

The Department believes that the motors it analyzed (open drip-proof, four-pole) serve as reasonable proxies for enclosed motors and two- and six-pole motors. The Department would expect, however, that an analysis that developed separate estimates for two, four, and six-pole motors would show somewhat different results, as would one that made discrete estimates for different horsepower ratings.

A simplifying assumption in the calculation is that each level of energy-efficiency improvement reflects an average attained by all new motors sold in each considered year. Thus, if a standard were set at a specific level of energy-efficiency improvement, the savings attributable to the standard are a function of the difference in efficiency relative to the base-case motor.

The Department assumed standards take effect in 2010 and calculated impacts for motors sold in the 2010-2030 period. The accounting model calculates total end-use electricity savings in each year with surviving motors (some of the motors sold in 2030 operate through 2040). The model uses a product retirement function to calculate the number of units in a given vintage that are still in operation in a given year. The retirement function assumes that there is a five-year range of individual motor lifetimes centered around the mean lifetime, and equal numbers of motors are retired in each of these five years. For example, for a seven-year average lifetime, twenty percent of motors are retired in five, six, seven, eight, and nine years respectively.

The Department calculated primary energy savings associated with end-use electricity savings using data from the EIA's Annual Energy Outlook 2006.[1] These data yield an average multiplier for end-use electricity to primary energy (power plant consumption) for each year for 2010–2020. The Department extrapolated the 2010–2020 trend for the 2021–2040 period.

For assessing direct economic impacts on end users, the Department used the incremental equipment costs for each energy-efficiency improvement level presented in Chapter 5. The Department assumed that the current estimated incremental costs remain the same in the 2010–2030 period of motor sales. In addition, the Department assumed that electricity prices remain at the projected 2010–2020 average through 2040.

The Department discounted future costs and benefits using a discount rate of seven percent, in keeping with "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs" issued by the Office of Management and Budget in 1992.[2] This rate approximates the marginal (inflation-adjusted) pre-tax rate of return on an average investment in the private sector in recent years.

6.1.1 Projection of Future Shipments

As discussed in Chapter 3, the past growth in annual shipments of the considered motors (including imported motors) is not known, but NEMA did provide confidential data on two-digit frame-size, fractional-horsepower motor sales to domestic customers by NEMA manufacturers, covering the period from 1971 to 2001. Based on the NEMA shipments data, the Department estimated the average annual growth rate to be 1.5 percent. Although the motors that the Department analyzed make up only around 20 percent of the motors covered by these data, industry experts suggest that growth in sales of the considered motors is likely to be similar to that of all fractional horsepower motors because the demand for both considered and non-considered fractional horsepower motors is closely tied to overall growth in the U.S. economy.

Several factors suggest that the growth in future sales may be slower than in the past. First, at a basic level, U.S. economic growth is expected to be slightly slower than that in the 1970–2000 period. Second, continuation of the current trend toward greater use of definite-purpose small motors would mean that sales of the general-purpose motors considered in this analysis would increase more slowly. Finally, foreign manufacturers of end-use equipment incorporating considered small motors may have lower production costs sufficient to gain market share at the expense of U.S.-based manufacturers, which would reduce U.S. domestic demand for small motors.

Based on the above considerations, the Department estimated impacts for two scenarios of average annual growth in shipments in the 2010–2030 period: one with 1.0 percent growth and the other with 1.5 percent growth. The Department refers to these two scenarios, respectively, as the "low shipments growth" and "high shipments growth" scenarios.

6.1.2 Base-case Efficiencies

In addition to the problem of forecasting future shipments, the Department is faced with uncertainty about product efficiencies in the base case. The Department has only limited knowledge regarding the past trend in efficiency because of insufficient data-availability. This imperfect historical knowledge means that it is difficult to establish a single base case efficiency forecast. For this reason, the Department used two base-case efficiency scenarios.

The perspective of the NEMA/SMMA working group and of other motor industry experts with whom the Department consulted is that the past 20–30 years have seen "very little to moderate" improvement in efficiency. Some gains occurred in the 1970s as electricity prices rose, and there has also been some spillover into small motors from efficiency improvement in integral horsepower motors. A number of manufacturers have introduced "premium-efficiency," small, polyphase motors. In the case of capacitor-start motors, there has been some growth in the use of more-efficient capacitor-run models, which to some extent has lessened the need to improve the more common induction-run models.

Following the above discussion, the Department identified the following two base-case efficiency scenarios: In the Low-Efficiency-Improvement base case, the average efficiency of motors sold in the 2010–2030 period is ¼ percent better than the current-base-case motors (e.g., 62.25 percent compared to 62 percent). In the Moderate-Efficiency-Improvement base case, the average efficiency is one point better than the current-base-case motors. The Department believes that these two cases plausibly bound future efficiency improvements in the absence of standards.

6.2 ESTIMATES OF POTENTIAL ENERGY AND CONSUMER IMPACTS

In this section, the Department provides estimates of the potential energy savings and national consumer impacts from potential motor efficiency improvements. The Department provides the results in graphical form for all design options, showing the energy savings as a function of design option in the form of a blue bar in units of "quads," quadrillion British thermal units, and showing net national economic impacts as squares (connected by a thin blue line) in Figures 6.1 through 6.3. The results for those design options that maximize energy savings while remaining economically justified are presented in tabular form for each economic forecast scenario and each set of engineering analysis data that the Department applied to the national impact analysis.

6.2.1 Capacitor-Start Motors

Figure 6.1 shows the results of the Department's national impact analysis for each of the Department's engineering design options for the four forecast scenarios for capacitor-start motors. For all scenarios, the M47 steel grade design option provides the greatest amount of potential energy savings. It also provides a positive national NPV for all forecast scenarios. Thus the results for this design option provide the Department's estimate of potential savings and potential net benefits from a standard for capacitor-start motors. As summarized in Table 6.1, the energy savings for motors sold between 2010 to 2030 ranges from 0.47 to 0.59 quad, and the national NPV ranges from $0.28 to $0.35 billion, depending on the forecast scenario.

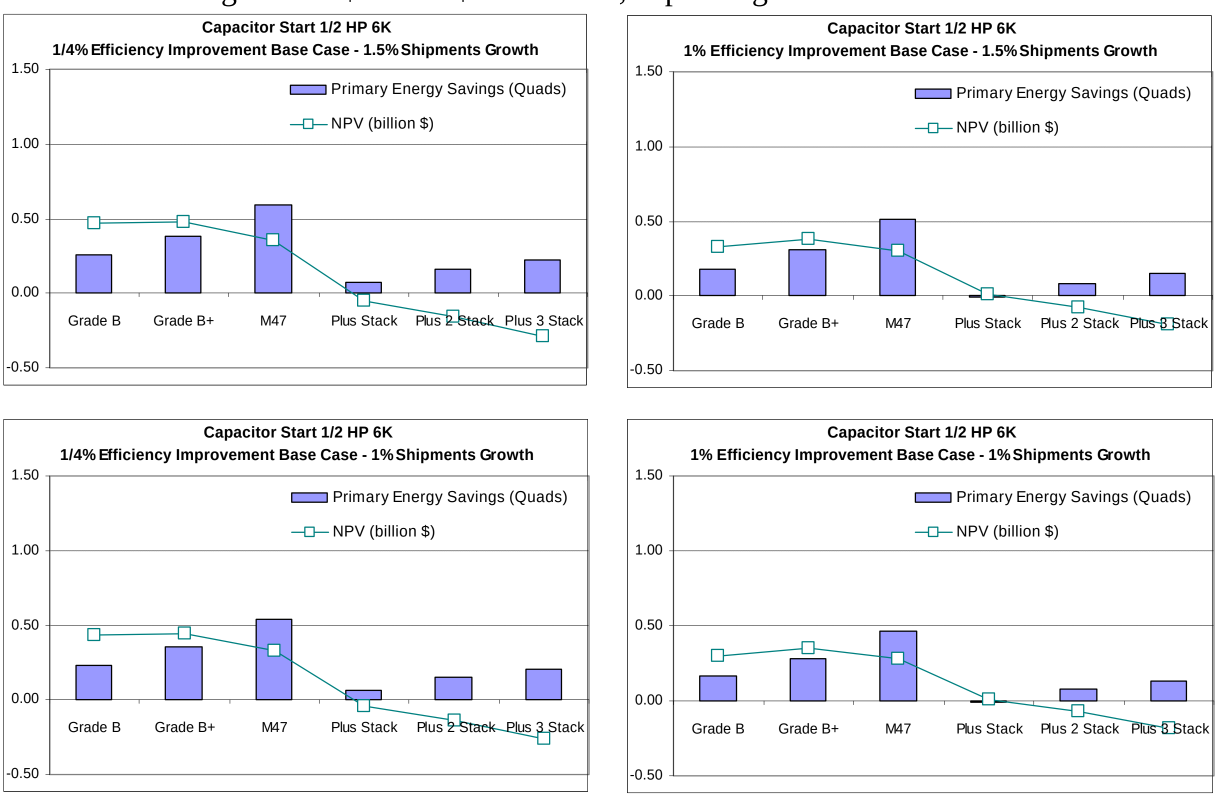

Figure 6.1 Capacitor-Start Motors, National Energy and Consumer Impacts, DOE Analysis

Figure 6.2 shows the same information as Figure 6.1 except for the NEMA/SMMA engineering data inputs rather than the Department's engineering data. The left portion of the plots represent the steel grade design options, while the right hand portion of the plots represent the results from the stack-length change design options. For the NEMA/SMMA data, the greatest energy savings is found for the design option with the largest stack-length change. But this option does not have positive national NPV for any of the forecast scenarios. However, three of the four scenarios have a positive national NPV for the smallest stack change option. For this design option and the NEMA/SMMA data, the energy savings ranges from 0.12 to 0.21 quad and a national NPV ranging from a negative $0.05 billion to a positive $0.04 billion as Table 6.1 details.

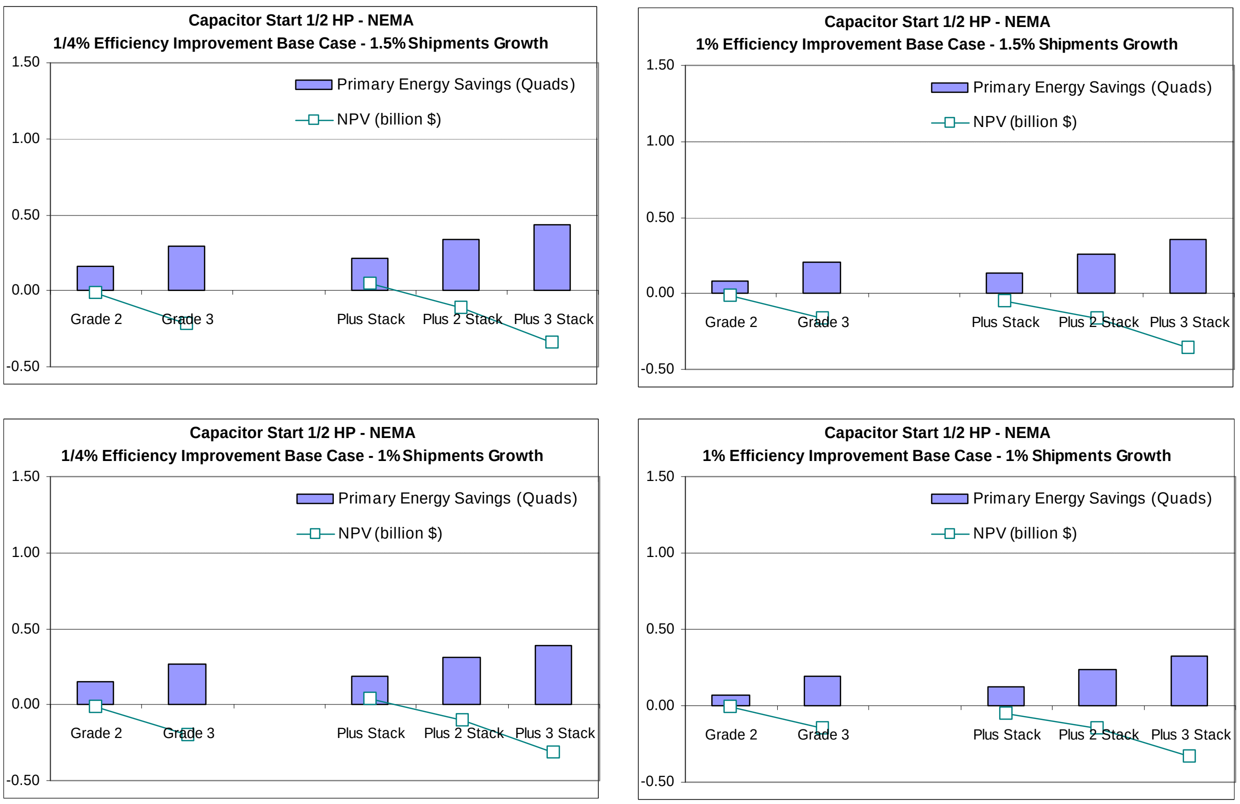

Figure 6.2 Capacitor-Start Motors, National Energy and Consumer Impacts, NEMA/SMMA data

Table 6.1 Cumulative Energy and Consumer Impacts of Energy Efficiency Improvement for Capacitor-Start, Induction-Run Motors Projected to be Sold in the 2010-2030 Period*

Future Scenario	**Energy Savings** (Quads)		**NPV** (Year 2005 dollars in billions, discounted at 7 percent to 2005)	
	DOE	**NEMA/ SMMA**	**DOE**	**NEMA/ SMMA**
Low-efficiency-gain base case, low shipments growth	0.54	0.19	0.33	0.04
Low-efficiency-gain base case, high shipments growth	0.59	0.21	0.35	0.04
Moderate-efficiency-gain base case, low shipments growth	0.47	0.12	0.28	-0.05
Moderate-efficiency-gain base case, high shipments growth	0.51	0.12	0.30	-0.05

* The values given for each scenario correspond to the design option with the combination of highest energy savings and most favorable consumer NPV.

6.2.2 Polyphase Motors

Figure 6.3 shows the results of the Department's national impact analysis for each of the Department's engineering design options for the four forecast scenarios for polyphase motors. As with capacitor-start motors, the M47 steel-grade design option provides the greatest amount of potential energy savings for all forecast scenarios. It also provides a positive national NPV for all forecast scenarios. Thus the results for this design option provide the Department's estimate of potential savings and potential net benefits from a standard for polyphase motors. As summarized in Table 6.2, the energy savings for motors sold between 2010 to 2030 ranges from 0.14 to 0.19 quad, and the national NPV ranges from $0.08 to $0.11 billion, depending on the forecast scenario.

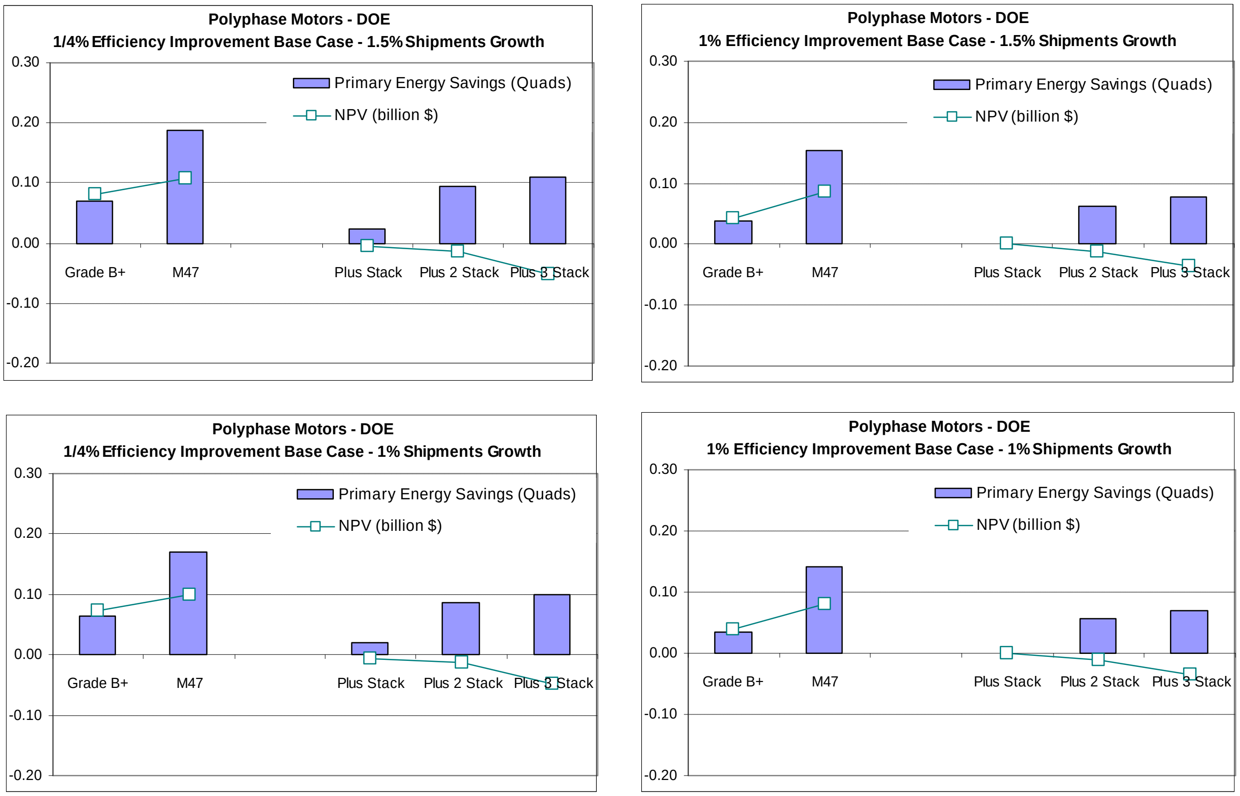

Figure 6.3 Polyphase Motors, National Energy and Consumer Impacts, DOE Analysis

Table 6.2 Cumulative Energy and Consumer Impacts of Energy Efficiency Improvement for Polyphase Motors Projected to be Sold in the 2010-2030 Period*

Future Scenario	**Energy Savings** (Quads)		**NPV** (Year 2005 dollars in billions, discounted at 7 percent to 2005)	
	DOE	**NEMA/ SMMA**	**DOE**	**NEMA/ SMMA**
Low-efficiency-gain base case, low shipments growth	0.17	Not Available	0.10	Not Available
Low-efficiency-gain base case, high shipments growth	0.19	Not Available	0.11	Not Available
Moderate-efficiency-gain base case, low shipments growth	0.14	Not Available	0.08	Not Available
Moderate-efficiency-gain base case, high shipments growth	0.15	Not Available	0.09	Not Available

* The values given for each scenario correspond to the design option with the combination of highest energy savings and most favorable consumer NPV.

6.2.3 Total Energy and Economic Savings

Given the national impact results for the capacitor start and polyphase motor product classes, the results based on the Department's engineering analysis indicate a potential energy savings ranging from 0.61 to 0.78 quad and a national NPV ranging from $0.36 to $0.46 billion.

Based on the NEMA/SMMA engineering data, estimates of national energy savings and national NPV are approximately 1/3 of the magnitude of the estimates based on the Department's engineering data (for capacitor-start motors).

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APPENDIX A. INFORMATION COLLECTION PROCESS ON USE OF SMALL MOTORS

Small motors are used in a variety of equipment. Easton Consultants identified 14 industrial categories and North American Industry Classification System (NAICS) categories and more than 45 categories of equipment that use small motors as defined. These include such diverse types of equipment as farm milking machines, industrial pumps, packaging machines, and machine tools.

The information collected for each category included the following three types:

Type 1 – Usage information

- Horsepower range,
- Average horsepower,
- Average hours of use,
- Qualitative information on specific applications (e.g., ambient conditions),
- Estimate of typical motor loading, and
- Other application-specific information.

Type 2 – Motor selection information

- Information on motor-purchasing practices and procedures by OEMs who use considered motors in their products,
- The degree to which changes in motor size related to improved efficiency may be incompatible with equipment designs used by OEMs,
- The degree to which motor efficiency is a significant consideration for OEMs, and
- Other selection-related information.

Type 3 – Quantitative (shipments) information

- Annual shipments of each considered motor type (capacitor-start and polyphase) for each category.

The Department used an information-collection process that followed a sequence of steps moving from general sources to specific sources, as needed. The Department proceeded step-by-step for each of the 14 categories as follows:

- **Step 1 –In-house expertise**. The Department started with its own expertise on each of the categories from past projects. The Department assembled this information as the starting point.
- **Step 2 --Industry associations**. The Department contacted the association or associations servicing each of the categories for general information on the industry, important players, industry characteristics and trends, and motor use.

- **Step 3 --Industry literature search**. The Department conducted a review of the relevant trade magazines and reports available publicly for relevant motor-related information on motor selection and use.
- **Step 4 --Company information review**. The Department explored the information available on one or two leading motor-using company web sites (particularly product specifications), requesting specifications from the sales department where not available on the Internet.
- **Step 5 --Expert assistance**. The Department worked with a former director of market research of a motor manufacturer who has extensive industry background.
- **Step 6 --Direct motor-using company informal discussion**. After the above sources had been fully utilized, the Department conducted a series of informal telephone interviews with equipment designers and engineers in each of the sectors. It designed these interviews to collect the specific information needed, and varied them for each category depending on the specifics of what was needed for that category. In these interviews the Department discussed:

    - Types of motors used in the particular equipment, to identify the approximate proportion of all motors that are considered motors,
    - Sizes of motors used,
    - Typical hours of operation of the motors,
    - Motor loading against its rated horsepower,
    - Role of energy efficiency in the decision and the rationale,
    - Health of the industry,
    - Technical changes expected that would affect motor use,
    - Typical life of the motor in this equipment's service, and
    - Other related subjects.

APPENDIX B. METHOD FOR ESTIMATING CONSIDERED SMALL MOTORS SHIPMENTS BY INDUSTRY SECTOR

As part of the effort to support the DOE project, "Development of Application Information for General Purpose Small Electric Motors Considered for Efficiency Standards," Easton Consultants conducted an analysis to estimate the shipments of considered small motors to each of 14 industry segments.

There is no single source that provides a measurement of the shipments of considered motors in the principal industries of use. As a result, the Department had to rely on a variety of sources of information, each of which provided only a piece of the puzzle. By integrating all of those available and then applying judgment, the Department has developed a reliable "first cut" estimate. The cornerstone of the estimates was first-hand research with a number of manufacturers of small-motor-using equipment.

The data sources used included the following:

1. Discussion with 4–10 equipment OEMs (product designers, engineers) in each of the small-motor-using equipment industries.
2. Survey of the small-motors manufacturers conducted by NEMA to measure the total shipments of considered motors.
3. The U.S. Census Bureau's Census of Manufacturers (1997), which measures equipment shipments and certain component usage by each of the principal small-motor-using industries.
4. Industry associations that cover the principal small-motor-using industries.
5. Catalogs of equipment using small motors.
6. Expert counsel from an individual who was formerly a market research manager with a leading motor manufacturer.
7. Past Easton projects on small-motor use, particularly the 1995 project conducted for DOE.

In the following chart, the Department has defined the role of each source of information in determining the estimates.

The Department compiled the initial set of shipments estimates in the year 2001 for this analysis. Subsequently, additional legislation resulted in more products being covered by energy conservation standards. Thus the Department adjusted its shipments estimates. The two key newly covered products are commercial clothes washers, and HVAC equipment from 240,000 to 760,000 Btu/hour. The Department assumed a reduction in shipments of 50 percent and 80 percent for considered small motors for these two applications as a result of the products being newly covered and made the corresponding adjustment to capacitor-start and polyphase motor shipments. This analysis provided new shipments estimates that the Department related to the earlier shipments with a shipments adjustment factor of 0.74 and 0.85 for capacitor-start and polyphase motors respectively.

Table B.1 Data and information source descriptions

Information Source	Description	Principal Value	Limitations	Importance of Source
OEM Interviews	Discussions with manufacturers of small motor using equipment	First hand inputs from engineers and designers who make the motor selection decisions in the user industries	The sample of OEMs was necessarily a small sample of the many companies using small motors.	Very High
NEMA Survey	Survey of principal small motors manufacturers	Provided a reliable measure of the total number of considered small motor shipments by size and type	Did not provide any information on the equipment in which the motors are used	High
Census of Manufacturers (1997)	Survey of U.S. Manufacturers	(1) Shipments of motor using equipment	Difficult in most cases to match equipment definitions with motor type	Low
		(2) Shipments of small motors to each industry	Data given for all shipments; considered motors not broken out.	High
Industry Associations	Organizations supporting industrial sectors	Information on sector structure (e.g. major companies), trends, economic health,	Most information could not be tied directly to motor use	Low
Equipment catalogs	Equipment descriptions for sales purposes	Often explicit as to the type and size of motors used	Most catalogs do not provide motor use information; only a few were useful	Low
Expert counsel	Review by an experienced market research head formerly with a motor manufacturer	"Reality check" on estimates	Motor manufacturers do not have good information on where small motors are used	Medium
Past Easton Reports	Easton files on small motor use from past projects	A variety of information, esp. from the 1995 report on small motors	Information generally dated	Medium

APPENDIX C. SMALL MOTORS DISCOUNT-RATE CALCULATIONS

The discount rate is the rate at which future expenditures are discounted to estimate their present value. The Department derived the LCC discount rates for considered small motors from data it collected for the LCC discount rate estimates in the distribution transformer rulemaking. Following financial theory, the cost of capital can be interpreted in three ways: 1) it is the discount rate that should be used to reduce the future value of cash flows to be derived from a typical company project or investment; 2) it is the economic cost to the firm of attracting and retaining capital in a competitive environment; and 3) it is the return that investors require from their investment in a firm's debt or equity. The Department primarily used the first interpretation. Most companies use both debt and equity capital to fund investments; for most companies, therefore, the cost of capital is the weighted average of the cost to the firm of equity and debt financing.

The Department estimated the cost of equity financing using the Capital Asset Pricing Model (CAPM). The CAPM, among the most widely used models to estimate the cost of equity financing, assumes that the cost of equity is proportional to the amount of systematic risk associated with a firm. For example, the cost of equity financing tends to be high when a firm faces a large degree of systematic risk, and the cost tends to be low when the firm faces a small degree of systematic risk.

The degree of systematic risk facing a firm and the subsequent cost of equity financing are determined by several variables, including the risk coefficient of a firm (beta, or *B*), the expected return on risk-free assets (R_f), and the additional return expected on assets facing average market risk (which is known as the equity risk premium, or ERP). The beta indicates the degree of risk associated with a given firm, relative to the level of risk (or price variability) in the overall stock market. Betas usually vary between 0.5 and 2.0. A firm with a beta of 0.5 faces half the risk of other stocks in the market; a firm with a beta of 2.0 faces twice the overall stock-market risk.

Following this approach, the cost of equity financing for a particular company is given by the equation:

$$k_e = R_f + (B \times ERP) \qquad \textbf{Eq. C.1}$$

where:

k_e = the cost of equity for a company,
R_f = the expected return of the risk-free asset,
B = the beta of the company stock, and
ERP = the expected equity risk premium, or the amount by which investors expect the future return on equities to exceed that on the riskless asset.

The cost of debt financing (k_d) is the yield or interest rate paid on money borrowed by a company (raised, for example, by selling bonds). As defined here, the cost of debt includes compensation for default risk and excludes deductions for taxes.

The Department estimated the cost of debt for companies by adding a risk adjustment factor to the current yield on long-term corporate bonds (the risk-free rate). This procedure is used to estimate current (and future) company costs to obtain debt financing. The adjustment factor is based on indicators of company risk, such as credit rating or variability of stock returns.

The discount rate of companies is the weighted-average cost of debt and equity financing, less expected inflation. The Department estimated the discount rate using the equation:

$$k = (k_e \times w_e) + (k_d \times w_d)$$

Eq. C.2

where:

k = the (nominal) cost of capital,
k_e and k_d = the expected rates of return on equity and debt, respectively, and
w_e and w_d = the proportion of equity and debt financing, respectively.

The real discount rate deducts expected inflation from the nominal rate.

The expected return on risk-free assets, or the risk-free rate, is defined by the current yield on long-term government bonds. The ERP represents the difference between the expected (average) stock market return and the risk-free rate. As shown in Table C.1, the Department used an ERP estimate of 5.5 percent, which it took from the Damodaran Online site (a private website, associated with New York University's Stern School of Business, that aggregates information on corporate finance, investment, and valuation).[1]

The Department calculated an expected inflation of 2.3 percent from the average of the last five quarters' change in Gross Domestic Product (GDP) prices.[2] The Department obtained the cost of debt, percent debt financing, and systematic firm risk from information provided at the Damodaran Online website.[1] Table C.1 shows average values across all private companies. However, the cost of debt, percent debt financing, and systematic firm risk vary by sector.

Table C.1 Cost of Capital Factors

Variable	Symbol	Average Value	Source
Risk-free asset return	Rf	5.5%	Bloomberg Professional[3]
Equity risk premium	ERP	5.5%	Damodaran Online[1]
Expected inflation	r	2.3%	U.S. Bureau of Economic Analysis[2]
Cost of debt (after tax)	kd	9.0%	Damodaran Online[1]
Percent debt financing	wd	27%	Damodaran Online[1]
Systematic firm risk	B	0.99	Damodaran Online[1]

Small motors are purchased and owned by commercial and industrial companies. The Department used a sample of 3,182 companies to represent small motor owners. It took the sample from the list of companies included in the Value Line investment survey and listed on the Damodaran Online website.[1,4] The Department obtained the cost of debt, the firm beta, the percent of debt and equity financing, the risk-free return, and the equity risk premium from Damodaran Online.[1]

The Department estimated the cost of debt financing for these companies from the long-term government bond rate and the standard deviation of the stock price.[5]

As previously mentioned, the cost of capital may be viewed as the discount rate that should be used to reduce the future value of typical company project cash flows. It is a nominal discount rate, since anticipated future inflation is included in both stock and bond expected returns. Deducting expected inflation from the cost of capital provides estimates of the real discount rate by small motor ownership category (see Table C.2).

Table C.2 Real Discount Rates by Small Motors Ownership Category

Ownership Category	SIC Codes*	Mean Real Discount Rate (%)	Standard Deviation (%)	Number of Observations
Industrial Companies	1 - 4	7.5	3.2	2409
Commercial Companies	5 - 8	7.3	4.7	1773

*SIC Codes refer to the U.S. Standard Industrial Classification system. Source: Lawrence Berkeley National Laboratory (LBNL) calculations based on firms sampled from the Damodaran Online website.

Because industrial companies purchase the bulk of small motors, the Department used the 7.5 percent discount rate for its LCC analysis.

The Department's approach for estimating the cost of capital provides a measure of the discount rate spread as well as the average discount rate. The Department inferred the discount rate spread by ownership category from the standard deviation, which ranges between 3.2 percent and 4.7 percent (Table C.2).

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